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CCC D1 Report on current adoption

Bert Smit, Wiepie Haagsma, Bas Janssens, Ruud van der Meer and Wil Hennen

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1 Introduction

1.1 Background

The EU has the goal of reducing its greenhouse gas (GHG) emissions in order to contribute to global climate change mitigation. In 2014, the EU decided to reduce its emission by 40% in 2030 compared to 1990. Agriculture is among the sectors under the non-Emissions Trading System (NETS), with an EU-wide goal of 30% reduction compared to 2005. The 30% reduction NETS goal is to be distributed unequally among Member States (MS) according to the Effort Sharing Regulation (ESR). The MS then have to decide how and in which NETS sectors their distributed domestic emission reduction goal should be achieved, and to which degree agriculture and agricultural sub-sectors should be involved.
At JRC the project 'Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA)' is designed to assess some aspects of a potential inclusion of the agricultural sector into the EU 2030 climate policy framework. In the context of possible reductions of non-CO2 emissions from EU agriculture, EcAMPA estimates production effects of various policy scenarios using the modelling framework of CAPRI. The EcAMPA project examines the adoption of different mitigation options in agriculture under different policy scenarios and their effects. Successful modelling of mitigation options requires information on various parameters including the adoption behaviour of farmers. So far, EcAMPA has modelled various mitigation options for reducing non-CO2 emissions, but also plans to include options that reduce CO2 emissions. Cover crops are one option that could be included in EcAMPA in the future.

Cover crops are crops grown for the protection of the surface which would otherwise be bare against erosion and nutrient losses. Catch crops are meant to 'catch' and immobilise available nitrogen remaining in the soil after the harvest of the main crop. They store the nitrogen in the plant tissue and thus prevent leaching into the groundwater. When a cover or catch crop is terminated (e.g. ploughed), the nitrogen becomes available again for the next main crop ("green manure"). A common typology also used by Eurostat distinguishes between three different types of soil cover: cover crops (to reduce soil erosion), green manure crops (which is any crop ploughed under to maintain soil organic matter and fertility) and catch crops (to prevent leaching; statutory catch crops can be undersown just before harvest of the preceding main crop).

Catch and cover crops (CCC), if managed right, can enhance mitigation of climate change through two main mechanisms: soil carbon sequestration (slowly building up the soil organic carbon content of the soil, a process that takes decades to reach equilibrium) and reducing emissions from fertiliser production (if CCC as green manure reduces fertiliser use in the following main crop). Albedo change is another potential mechanism by which CCC could enhance mitigation (Kaye & Quemada, 2017). While large uncertainties regarding the extent of the potential mitigation by CCC remain, reducing these uncertainties is not the focus of this study. This study focuses on the considerable lack of information on how CCC are being implemented at the farm level and on the reasons why farmers are not growing CCC more. Many farmers do not adopt CCC and therefore there is a potential to improve climate change mitigation by increasing CCC adoption. An understanding of the reasons why farmers do not adopt more CCC is thus essential. If farmers are using CCC, it is important to understand not only why they are doing so but also the details of CCC management practices (which may or may not support mitigation) and reasons for the chosen management practices. By improving the understanding of these issues, the study can contribute to better modelling of mitigation options in agriculture, policy design and evaluation.

Apart from climate change mitigation, CCC can also have other environmental and agronomic benefits. These include reducing leaching, erosion, and improving soil health, some of which may also improve adaptation to climate change (Kay & Quemada, 2017). In addition, cover crops have a role in pest management as they can break pest cycles and control weeds. A green manure effect can come from mineralisation of CCC residues, and even more from legume CCC. Alternatively, CCC can be harvested and used or sold as livestock feed. Different species are suitable to be used as CCC and often farmers grow a mix of several species to enhance various benefits.

However, CCC can also have negative agronomic and economic effects, some of which may help explain low adoption. CCC may increase pests and diseases or become weeds themselves in the future. Labour requirements may increase and there is a cost associated with buying seed and establishing and incorporating CCC. In dry weather, establishment may be challenging. CCC may have a yield effect on the following main crop. Whether they have an effect seems to depend on the CCC and main crop, and on the use of fertiliser. For example, according to one review of the evidence, no effects on soybean yield have been found, but maize yield increased significantly when legumes were used as CCC and decreased significantly when non-legumes were used as CCC (Alvarez et al., 2017). Apart from yield effects, the sowing of CCC can increase farmers cost (purchase of seeds, cost of cultivation) and work. Water depletion could also become a problem as a result of growing CCC in low rainfall areas. As with yield, the effects of CCC on leaching are also ambiguous (Alvarez et al., 2017; Miguez & Bollero, 2005; Tonitto et al., 2006; Valkama et al., 2015).

These various costs and benefits influence the decision of farmers to grow or not grow CCC. Apart from these costs and benefits, political incentives have been put in place in many cases that exert an influence on that decision as well, for example greening, the Nitrate Directive, or Rural Development Programs. Finally, there may be other economic, sociological and psychological factors at play, too (Pe'er et al., 2016).

1.2 Problem definition

In task 1 of the project, the central question is to collect all available information on the current and past adoption and mitigation of CCC in the EU. This report provides definitions and details of the different types of CCC, their management practices, adoption and mitigation potential in the different farming systems and regions of the EU.

1.3 Definition of catch and cover crops

As described in 1.1, cover crops are crops grown in periods and on soils which would otherwise be fallow. Cover crops can provide a number of ecosystem services (agronomic and ecological) via agro-ecological functions. Primarily these may be: (i) to reduce leaching, (ii) to provide nitrogen to the next crop, (iii) to reduce soil erosion, (iv) to improve soil structure and soil hydric properties, (v) to reduce parasite pressure on crops [1], (vi) to prevent weed growth, and (vii) to increase the biodiversity of the farming landscape and environment (wildlife, bees, etc.). Catch crops can fulfil several different agro-ecological functions simultaneously (Justes (2017), Kaye and Quemada (2017), Blanco-Canqui et al. (2015), Unger and Vigil (1998), Dabney et al. (2001)).

According to The Glossary of Soil Science Terms, a cover crop is defined as a 'close-growing crop, that provides soil protection, seeding protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards. When ploughed under and incorporated into the soil, cover crops may be referred to as green manure crops.' A catch crop is defined as: '(i) a crop produced incidentally to the main crop of the farm and usually occupying the land for a short period; (ii) a crop grown to replace a main crop that has failed' (Soil Science Society of America, 2008).

The term 'cover crop' is broadly used for crops grown in between two main crops in time or between or under a main crop in space (like trees). Cover crops represent crops with no- or minor financial benefits. The specific term 'catch crop' is used for a cover crop which is grown for 'catching' nitrogen to prevent nitrogen leaching (Thorup-Kristensen et al., 2003).

In most studies on the diverse effects of cover crops, the biomass of the cover crop is reported to be left on the field. A few studies indicate no adverse effect on soil and crop production from grazing and haying

[1] The term 'catch crops' is also used for the management of nematodes through certain crops, like Tagetes. The nematode is killed after entering the root. This is a specific function of Tagetes and other nematode 'catch' crops to improve the soil health status besides other functions like being a green manure.

of the cover crop. This suggests a financial benefit for cover crops besides other benefits (Blanco-Canqui et al., 2015). This implies that a cover crop can be used for fodder (grazing or haying) or as a biofuel. In such cases, adding some added value is a secondary aim besides the first aim(s), benefiting from the agro-ecological functions listed above. However, in most cases, they are not destined to be harvested and are destroyed (or their growth is stopped) before the next main crop is planted. Their biomass is returned to the soil to promote recycling of nutritional components for the next crop and improve the physical, chemical and biological fertility of the soil. In case of using the biomass for fodder or biofuel purposes, when this application is extended to a full growing season, the crop is no longer categorised as a cover crop but as a green harvested or biofuel crop.

In the definition, the season is not mentioned, so cover crops can be grown in every season of the year. In practice, cover crops are divided in summer and winter cover crops, referring to the season in which they are grown. Summer cover crops are applied when the next main crop is a winter crop (e.g. winter wheat), winter cover crops when the next main crop is a spring crop (e.g. spring wheat). Cover crops are usually sown after the previous main crop has been harvested, although they may also be undersown with the main crop. [2] Examples of undersown cover crops are grass or clover in cereals and grass in maize. After harvest, these cover crops are generally sown between July and September and destroyed between November and February of the following year. Their growth period therefore ranges from 2 to 6 months, depending on crop rotations and regions. They may be destroyed naturally by frost, mechanically (chopping, ploughing, surface stubble ploughing) or chemically, by the application of a systemic foliar herbicide (glyphosate, for example), depending on the type of crop and the maturity of the plant cover, but also the regulations in force, which, in numerous cases, prohibit chemical destruction processes. In some cases, a cover crop stays at the field for a full season, replacing a main crop in that year (but in general not giving a direct financial benefit).

In diagrams 1.1 and 1.2, the concept of 'cover crops' is illustrated. In a crop rotation, the fallow period is the period between the harvest of the main crop (sown for the purpose of harvesting) and the sowing of the next (diagram 1.1). Depending on the harvesting and sowing dates of the main crops, it can last from several days in the case of late harvest followed by sowing of a winter crop, to several months (up to 9 months) in the case of a spring crop. During this period, soil that is left 'bare' (without plants), especially in the event of a long fallow period, can significantly increase the risk of leaching of nitrate into aquifers. The use of a cover crop as a nitrate-trapping "catch crop" (Diagram 1.2) can reduce this phenomenon of nitrate transfer in variable proportions depending on the soil and climate conditions, as well as the cropping system.

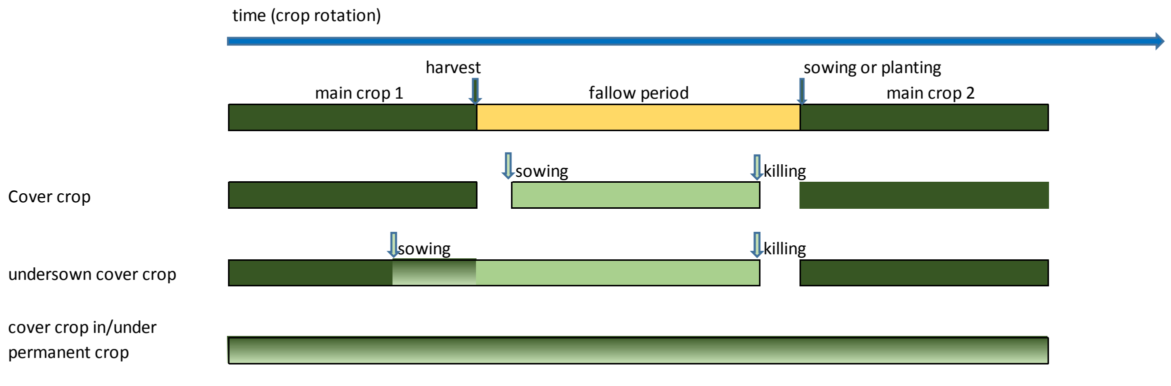

Diagram 1.1 Illustration of the position of cover crops in a crop rotation (based on figure 1.1 in Justes (2017) 'Cover crops for sustainable farming')

[2] An estimation for the Netherlands is that 25% of the cover crop is undersown, mainly grass under maize and grass or clover under cereals.

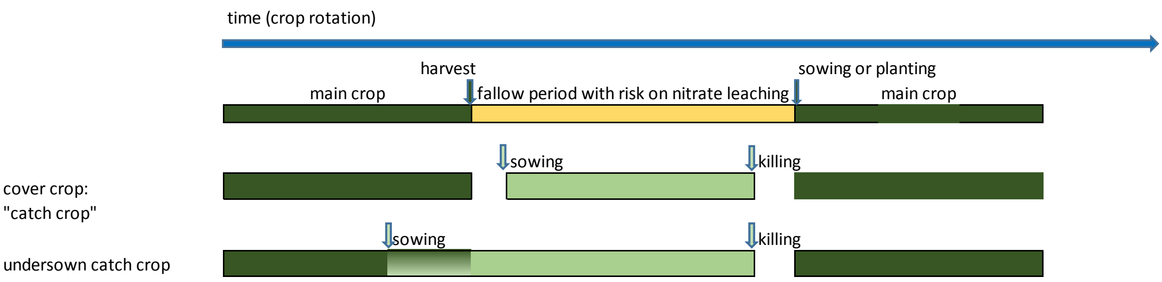

Diagram 1.2 Illustration of the position of a cover crop called 'catch crop' in a crop rotation relative to a sensitive period in terms of nitrate leaching (based on figure 1.1 in Justes (2017), 'Cover crops for sustainable farming')

In this study, the term 'catch and cover crops' (CCC) is used for all the types of catch and cover crops and green manures, as described in the previous paragraphs. Farmers in the EU are stimulated to grow such crops in the 'Greening' regulations of the EU, which were introduced in 2015. In one of these regulations, ecological focus areas play a major role (See overview 1.1 and Appendices 2 and 3).

Overview 1.1 Ecological Focus Areas as a part of the Greening measures in CAP

The 2013 CAP reform introduced into Pillar 1 a payment for a compulsory set of 'greening measures', accounting for 30% of the direct payments budget (Alliance Environnement and the Thünen Institute, 2017). These measures are intended to enable the CAP to be more effective in delivering its environmental and climate objectives and to ensure the long-term sustainability of EU agriculture by safeguarding natural resources and achieving a more balanced economic and environmental performance. One of the three practices to fulfil this requirement consists of the Ecological Focus Areas (EFA) – to manage at least 5% of the arable land of farms with more than 15 hectares of arable land as an EFA, comprising a combination of management practices or landscape features as set out in the regulation and applied by Member States (to safeguard and improve biodiversity on farms primarily, cited from Alliance Environnement and the Thünen Institute, 2017). The ecological focus area should consist of areas directly affecting biodiversity such as land lying fallow, landscape features, terraces, buffer strips, afforested areas and agro-forestry areas, or indirectly affecting biodiversity through a reduced use of inputs on the farm, such as areas covered by catch crops and winter green cover (EU, 2013). As such, the Greening obligation could support the cultivation of CCC throughout the EU.

1.4 Climate change mitigation potential of different CCC

Catch and cover crops (CCC), if managed right, can enhance mitigation of climate change through several mechanisms: soil carbon sequestration, avoiding losses of nitrogen and fixing atmospheric nitrogen by leguminous CCC. As a consequence, the use of N-fertiliser can be reduced leading to reduced GHG emissions from fertiliser production. Another potential mechanism could be the surface Albedo change (Kaye & Quemada, 2017). The calculations on this latter mechanism are preliminary and additional research on this topic is necessary. Therefore this mechanism is not worked out in this study.

1.4.1 Effect of cover crops on reducing CO2 emission by enhanced carbon sequestration

There is an extensive body of research on the potential of improved land management practices resulting in soil carbon stock increase (C sequestration) (Paustian et al. 2016). On a farm level scale, this can be achieved by two main mechanisms: i) reducing C losses by reducing the decomposition rate in the soil or ii) the increase of organic matter production by capturing CO2 on-farm and thus storing it in the soil. When the two mechanisms are combined successfully, they might lead to a positive net removal of C from the atmosphere (Paustian et al. 1997). One of the land management practices which can achieve an increase in soil C sequestration on-farm, practicing mechanism (ii), is growing cover crops (Poeplau & Don, 2015). Poeplau & Don (2015) conducted a meta-analysis on the potential of cultivating cover crops for carbon sequestration in agricultural soils. One of their main conclusions was that cover crops are an important land management practice to increase C stocks. Using data from 37 different sites they calculated an annual change rate of 320 ± 8 kg C per ha per year. The meta-analytical estimate of global C sequestration by using cover crops from Poeplau & Don (2015) is comparable to values tabulated by several other references mentioned by Kaye & Quemada (2017). The C sequestration rate of 320 ± 8 kg C per ha per year is equal to a mitigation rate of 1,170 ± 290 kg CO2e per ha per year. [3]

C sequestration has a finite lifespan because it can reach a steady state. Models and measurements suggest that this process will take at least 50 years and may even last 150 years until this steady state is reached (Poeplau & Don, 2015, Schipanski et al. 2014).

C stocks can decrease through (starting with more intensive) tillage and a lower production of organic matter than the amount of mineralised organic matter. An example of a C stock decrease is renewal of permanent grass through ploughing and resowing grass. Necpálová et al. (2014) found after grassland renewal a decreased soil organic carbon (SOC) by 32.2 t per ha in the 2.5 years following ploughing; the difference developed almost entirely (86%) in the first four months. This example is not about cover crops, but is demonstrates the vulnerability of the C sequestration process. Cover crops can add to this process, but that will only be successful when the crop and the soil are optimally managed from this point of view. Estimations on the effects of C sequestration in practice therefore depend on the measure in which crop and soil management have been applied optimally. This part of the benefits of cover crops are probably not always reached in practice.

1.4.2 Effect of cover crops on reducing CO2 emission by reduced N-fertilisation and -emissions

Besides effects on C-sequestration, cover crops have an influence on the 'nitrogen cycle', the subject of this section. Cover crops can have a direct and an indirect effect on the emission of the greenhouse gas N2O. N2O has a Global Warming Potential 298 times greater than CO2 (IPCC, 2007).

The behaviour of nitrogen in the soil is complex. Understanding these processes is essential to understand the effect of the role of CCC on climate change mitigation. Lamb et al. (2014) give an excellent description in their book 'Understanding nitrogen in soils', which is the basis for the text in this section.

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another. The route that N follows in and out of the soil system is collectively called the 'nitrogen cycle' (figure 1.1). The nitrogen cycle is biologically influenced. Biological processes, in turn, are influenced by prevailing climatic conditions along with the physical and chemical properties of a particular soil. Both climate and soils vary greatly across the EU and affect the N transformations for the different areas.

In the following, attention is given to the inputs of N for plant growth, nitrogen transformation, nitrogen losses and misconceptions on the nitrogen cycle.

1.4.2.1 Inputs of N for plant growth

Nitrogen is the most important nutrient for plant growth and comes from different sources:

[3] The table in the article by Kaye and Quemada mentions 1,170 ± 390 kg CO2e per ha per year, but the figure of 390 is questionnable.

- The atmosphere
- Biological fixation
- Atmospheric fixation
- Precipitation (deposition)
- Industrial fixation – commercial fertilisers
- Soil organic matter (mineralisation)
- Crop residues (mineralisation)
- Animal manures (mineralisation)

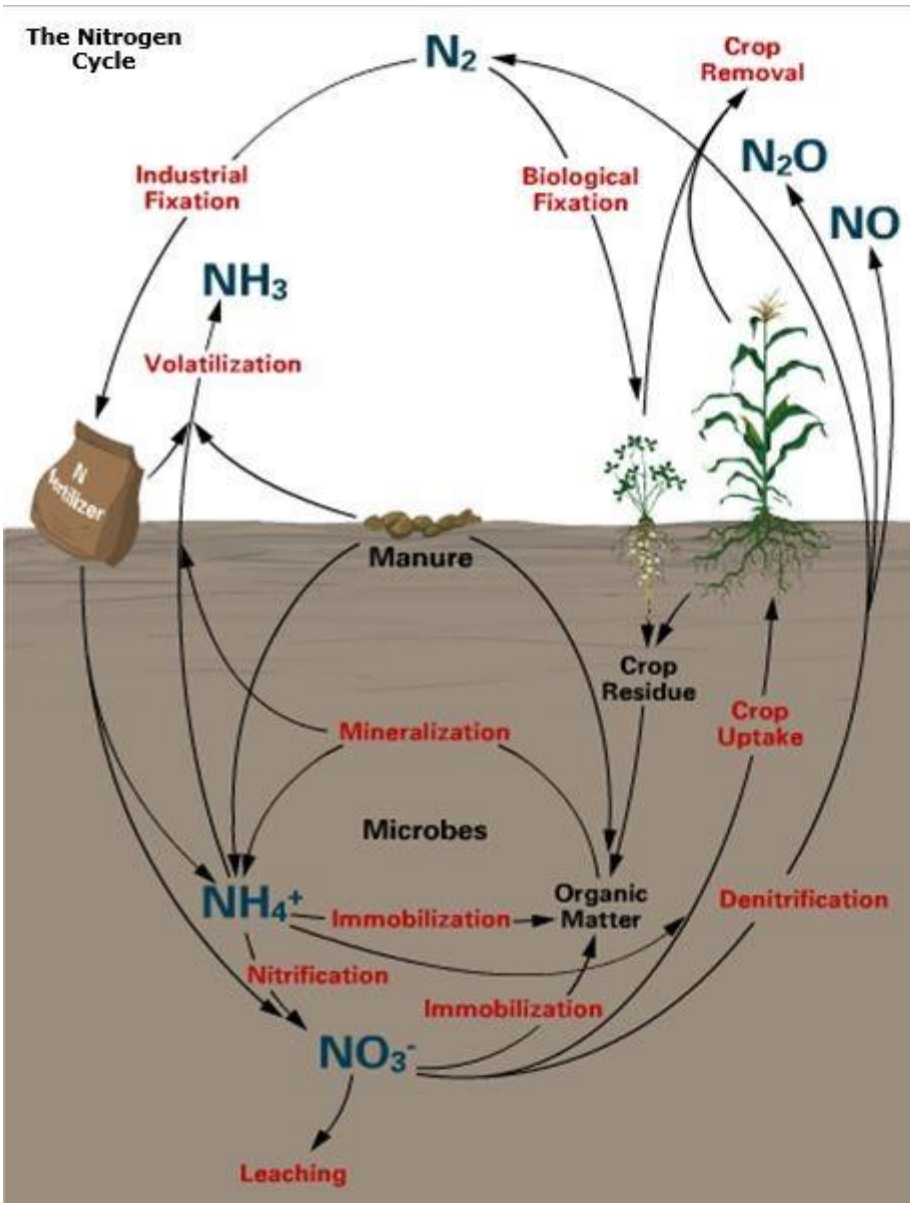

Figure 1.1 The nitrogen cycle in the soil (courtesy of Cornell University, Cooperative Extension)

Atmospheric N is the major reservoir for N in the N cycle (air contains 79% N2 gas). Although unavailable to most plants, large amounts of N2 can be used by leguminous plants via biological N fixation. In this biological process, nodule-forming Rhizobium bacteria inhabit the roots of leguminous plants and through a symbiotic relationship convert atmospheric N2 to a form the plant can use. The amount of N2 fixed by legumes into usable N can be substantial, with a potential for several hundred kg N per ha per year to be fixed in an alfalfa crop. Any portion of a legume crop that is left after harvest, including roots and nodules, can supply N to the soil system when the plant material is decomposed. Several nonsymbiotic organisms exist that fix N, but N additions from these organisms are quite low (1-5 kg per ha per year). In addition, small amounts of N are added to soil from precipitation (deposition). In the EU, this amount averages between 1-45 kg per ha per year.

Commercial N fertilisers are also derived from the atmospheric N pool. The major step is to combine N2 with hydrogen (H2) to form ammonia (NH3). Anhydrous ammonia is then used as a starting point in the manufacture of other nitrogen fertilizers. Anhydrous ammonia or other N products derived from NH3 can then supplement other N sources for crop nutrition. Nitrogen can also become available for plant use from organic N sources (animal manures and other organic wastes). But first these organic sources must be converted to inorganic forms before they are available to plants. The amount of N supplied by manure will vary with the type of livestock, handling, rate applied, and method of application.

Crop residues from non-leguminous plants also contain N, but in relatively small amounts compared with legumes. Nitrogen exists in crop residues in complex organic forms and the residue must decay (a process that can take several years) before N is made available for plant use.

Soil organic matter is also a major source of N used by crops. Organic matter is composed primarily of rather stable material called humus that has collected over a long period of time leading to C sequestration. Easily decomposed portions of organic material disappear relatively quickly, leaving behind residues more resistant to decay.

1.4.2.2 Nitrogen transformations

Nitrogen, present or added to the soil, is subject to several changes (transformations) that dictate the availability of N to plants and influence the potential movement of $NO3^-$-N (nitrate) to water supplies.

Organic N that is present in soil organic matter, crop residues, and manure is converted to inorganic N through the process of mineralisation. In this process, bacteria digest organic material and release $NH4^+$-N (ammonium). Ammonium-N has properties that are of practical importance for N management. Plants can absorb ammonium. Ammonium also has a positive charge and therefore, is attracted or held by negatively charged soil and soil organic matter. This means that ammonium does not move downward in soils. Nitrogen in the ammonium form that is not taken up by plants is subject to other changes in the soil system. Nitrification is the conversion of ammonium to nitrate .

Nitrification is a biological process and proceeds rapidly in warm, moist, well-aerated soils. Nitrate-N is a negatively charged ion and is not attracted to soil particles or soil organic matter like ammonium. Nitrate-N is water soluble and can move below the crop rooting zone under certain conditions.

Denitrification is a process by which bacteria convert nitrate to N gases that are lost to the atmosphere. Denitrifying bacteria use nitrate instead of oxygen in the metabolic processes. Denitrification takes place in waterlogged soil and with ample organic matter to provide energy for bacteria. For these reasons, denitrification is generally limited to the topsoil. Denitrification can proceed rapidly when soils are warm and become saturated for 2 or 3 days.

A temporary reduction in the mount of plant available N can occur from immobilisation (tie up) of soil N. Bacteria that decompose high carbon-low N residues, such as corn stalks or small grain straw, need more N to digest the material than is present in the residue. Immobilisation occurs when nitrate and /or ammonium present in the soil is used by the growing microbes to build proteins. The actively growing bacteria that immobilise some soil N also break down soil organic matter to release available N during the growing season. There is often a net gain of N during the growing season because the additional N in the residue will be the net gain after immobilisation-mineralisation processes.

1.4.2.3 Nitrogen loss from the soil system

There are different ways in which the soil system can loose part of its available nitrogen:

- Crop removal
- Leaching
- Denitrification
- Volatilisation
- Soil erosion and runoff

Substantial amounts of N are lost from the soil system through *crop removal*. Crop removal accounts for a majority of the N that leaves the soil system. However, this part of the N removed will not be lost to ground- or surface water or to the air (in this stage of the chain process).

In contrast to the biological transformations previously described, loss of nitrate by *leaching* is a physical event. Leaching is the loss of soluble nitrate as it moves with soil water, generally excess water, below the root zone. Nitrate-N that moves below the root zone has the potential to enter either groundwater or surface water through tile drainage systems. This nitrate in water denitrifies and causes N2O fluxes to the atmosphere.

Coarse-textured soils have a lower water holding capacity and, therefore, a greater potential to lose nitrate from leaching when compared with fine-textured soils. Some sandy soils, for instance, may retain only 1/3 of the soil volume while some silt loam or clay loam soils may retain up to 2/3 of the volume. Nitrate-N can be leached from any soil if rainfall or irrigation moves water through the root zone.

Denitrification can be a major loss mechanism of nitrate when soils are saturated with water for 2 or 3 days. Denitrification causes N fluxes, among which the GHG N2O, from soil to atmosphere. Nitrogen in the ammonium form is not subject to this loss. Management alternatives are available if denitrification losses are a potential problem. Significant losses from some surface-applied N sources can occur through the process of *volatilisation*. In this process, N is lost as ammonia (NH3) gas. Nitrogen can be lost in this way from manure and fertiliser products containing urea. Ammonia is an intermediate form of N during the process in which urea is transformed to ammonium. Incorporation of these N sources will virtually eliminate volatilisation losses. Loss of N from volatilisation is greater when soil pH is higher than 7.3, the air temperature is high, the soil surface is moist, and there is a lot of residue on the soil.

Nitrogen can also be lost from agricultural lands through *soil erosion and runoff*. Losses through these events do not normally account for a large portion of the soil N budget, but should be considered for surface water quality issues. Incorporation or injection of manure and fertiliser can help to protect against N low through erosion or runoff. Where soils are highly erodible, conservation tillage can reduce soil erosion and runoff, resulting in less surface low of N.

1.4.2.4 Consequences for the concept of cover crops

The processes of leaching and denitrification as described above can be influenced by CCC and lead to enhanced N2O emission. [4]

Leaching

Nitrate is always present in the soil solution and will move with the soil water. Inhibiting the conversion of ammonium to nitrate can result in less N loss and more plant uptake; however, it is not possible to totally prevent the movement of some nitrate to water supplies, but sound management practices can keep losses within acceptable limits. The potential losses by leaching in a fallow soil are influenced by (i) the amount of N left in the soil after the harvest of the preceding main crop, (ii) the amount of N left in the crop residues, (iii) the mineralised nitrate from organic N in the soil, (iv) precipitation surplus and (v) soil type:

[4] Like described in section 1.4.2.3, volatilisation is the loss from some surface-applied N sources. In this process, N is lost as ammonia (NH3) gas. This gas is not mentioned as a greenhouse gas. The loss of N by volatilisation can be decreased by using different types of N sources and different types of incorporation. These losses cannot be decreased by using CCC and are therefore not described in this section.

i. The amount of nitrate left in the soil after the harvest of the preceding main crop; main crops differ in the amount of N left in the soil after harvest. The ratio between the N uptake and the available N is important. This can be expressed in a N-Utilization Ratio (table 1.1). This ratio can vary from 0.4 to over 0.8. Short growing vegetable/industrial crops with poor rooting system have a low ratio (0.4) and a crop like winter wheat with a deep intensive rooting system has a high ratio (>0.8). When for example the ratio is 0.6, 40% of the N amount from fertilisation is left in the soil and can be lost through leaching and/or denitrification with rainfall in a fallow period. CCC can take up at least part of this N;

ii. The amount of N left in the crop residues; main crops differ in the amount of N left in the crop residues (table 1.1), depending on the biomass and the N content. CCC can take up (part of) the mineralised N from these residues;

iii. The mineralised nitrate from organic N in the soil; this amount strongly depends on the weather conditions during and after the growing season of the main crop. It will be high after an early harvested crop with warm and moistured conditions. CCC can take up this nitrate;

iv. Precipitation surplus; as described above, leaching depends on the amount of water that passes the rooting zone during and after the growing period of the main crop. The effect of a CCC on prevention of N-leaching therefore depends on the precipitation surplus, creating a net downward flow of water through the soil;

v. Soil type; as described above, leaching depends on the soil type, especially on the structure whether it is fine or coarse.

Table 1.1 The N-Utilization-Ratio (NUR) and the amount of N in crop residues of some crops in farming systems in North Western Europe (Vlaar et al., 2008)

NUR	N in crop residues (kg N/ha)			
	0-50	50-100	100-150	>150
<0.4	Radish			
0.4-0.5	Onion, lettuce			
0.5-0.6	Potato	leek	cauliflower	broccoli
0.6-0.7	maize			
0.7-0.8	carrot		White cabbage, sugar beet	
>0.8	Winter wheat			Red cabbage

The highest risks on N leaching and hence an important potential for CCC on climate change mitigation have to be taken into account after crops with a low NUR and/or crops with high N amounts in crop residues. In this aspect, a CCC has an effect in two dimensions: Firstly, it leads to a decreased loss of nitrogen to the air and to ground- en surface water and, as a consequence to a less rapid climate change (see further on in this section) and secondly, it leads to a decreased N-fertiliser use in the following crop and, as a consequence to a lower use of energy for N-fertiliser manufacturing.

Denitrification

CCC take up nitrate and water from the soil so a lower denitrification can be expected leading to lower N2O fluxes to the atmosphere. On the other hand the terminated or incorporated C and N in the CCC biomass may lead to higher mineralisation, nitrification and denitrification. Legumes with a high N content can cause a high nitrification and subsequent denitrification and a higher risk on N2O fluxes. Therefore good agricultural practice is required to prevent these losses (see section 3.3.4).

The cultivation of cover crops can have an effect on the emission of greenhouse gasses (GHG). Nitrous oxide (N2O), one of the GHG, has been calculated to form the largest contribution to global warming from agricultural land use systems. N2O is a greenhouse gas with a long lifespan in the atmosphere, therefore it has a Global Warming Potential 298 times greater than CO2 (USEPA 2013; IPCC 2007; Robertson et al. 2000). There is no academic consensus about the effect of cover crops on nitrous oxide emissions (Basche et al. 2014), N-holding gasses which result from denitrification. Emissions from terrestrial ecosystems depend on variables such as available mineral N, soil water content, labile carbon and soil physical properties (Davidson et al. 2000, Venterea et al. 2012), processes on which cover crops have an influence. Several authors state that the net impact of cover crops on nitrous oxide is not yet well described (Cavigelli et al. 2012). Basche et al. (2014) conducted a meta-analysis on the potential increasing or decreasing effects of cover crops on N2O emissions. The authors reviewed 26 peer reviewed articles which included 106 observations on effects of CCC on N2O emissions. 40% of the observations indicated a net decreasing N2O effect whilst using cover crops, 60% of the observations indicated a cover crop effect of increasing N2O effects. Several factors modified the magnitude of effect of cover crops on N2O emissions: N-fertiliser rates, soil incorporation, period of measurements and rainfall. The general conclusion of the paper is that cover crops have potential to reduce N2O emissions when non-legume CCC-species are used and CCC-residues are not being incorporated in the soil. Kaye and Quemanda (2017) concluded in their review that when CCC alter N2O fluxes compared to fallow, the emission of N2O may increase or decrease by about 0.01 g N/m2/yr. This corresponds to 47 kg CO2 eq./ha/yr. They also mention the N2O emission from soils for the seed production of the CCC. This amounts 16 kg CO2 eq./ha/yr for legume CCC to 40 kg CO2 eq./ha/yr for non-legume CCC.

It is known that the application of high nitrogen fertiliser rates contributes to N2O emissions (Stehfast and Bouwman, 2005). In the study of Basche et al. (2014) this is confirmed; N rates explained most of the variability in N2O emissions. The authors describe a significant interaction between cover crop type (legume or non-legume) and N rates.

1.4.2.4 Reduced N fertiliser use

Cash crops followed by a CCC can take advantage from the mineralised N from the CCC. As a consequence, the fertiliser N rate can be reduced. Production of synthetic N fertiliser is a large source of energy use. The amount of N from CCC mineralised and available for the following crop is variable and depends on the produced biomass, its N content, the mineralisation rate (C:N ratio), the moment of destruction, the length of time between destruction and N uptake of the following crop and the weather conditions during that period.

Kaye and Quemada (2017) concluded from studies in USA and Spain an average fertiliser use reduction of 50 kg N/ha in the main crop after a legume CCC. This correponds with a reduction of 195 kg CO2 eq./ha/yr using a mean value of 3.9 kg CO2 eq./kg N fertiliser (Camargo et al., 2013). For non-legumes they do not calculate with a reduction of fertiliser use.

1.4.2.5 Fuel use

Growing a CCC increases the number of field operations that farmers must make, mainly for sowing/planting the CCC and for destruction the CCC mechanically or with a herbicide (c, 2017; WUR-PAGV, Handbook Soil and Fertilisation). No-till drilling of a CCC requires about 7 L/ha of diesel fuel, which amounts to 23 kg CO2 e/ha, while a herbicide application requires about 5 kg CO2 e/ha (Camargo et al. 2013), for a total of 28 kg CO2 e/ha/year. Kaye and Quemada used this as a typical value and then used a range of possible planting and killing approaches to generate the expected variation in CO2 e from farm operations fuel. A low estimate (10 kg CO2 e/ha) was made for planting a winter-killed CCC by broadcasting seed and incorporating with a simple harrow (Camargo et al. 2013). A high estimate (100 kg CO2 e/ha) was made for a CCC planted into a seedbed prepared with a chisel plow and cultipacker and then killed by mowing.

1.4.2.6 Herbicide use

If the CCC is destructed with a herbicide, this does not only involve an additional field operation, leading to extra fuel consumption (1.4.2.5). Another aspect is the energy use for preparing such a herbicide (manufacturing, packaging and transportation). E.g. the production of glyphosate, the main herbicide for killing a CCC, requires 474 MJ/kg active ingredient (a.i.) (Audsley et al., 2009). A factor of 0.069 kg CO2 equivalent per MJ pesticide energy can be used to convert this figure to the Global Warming Potential

(100 years) (Audsley et al., 2009), which gives a figure of 32.7 kg CO2e per kg a.i. Assuming a dose of 1 kg a.i. per ha for killing the CCC (derived from Van Zeeland and Van der Weide (2000)), that would imply an additional effect of 32.7 kg CO2e. However, this effect has the same order of magnitude as the effect of mechanical CCC destruction. This leads to a somewhat higher estimation for fuel use including CCC destruction than originally given by Kaye and Quemada (2017).

1.4.2.7 Summary of expected climate change mitigation effects of cover crops

The description of the mechanisms above shows how complex the processes in the soil are. However, Kaye and Quemada (2017) succeeded to create a global overview of the climate change mitigation effects of legume and non-legume cover crops (table 1.2). The most important terms in the mitigation potential calculations are soil carbon sequestration and reduced fertiliser use after legume cover crops. The total average climate change mitigation effect of growing a cover crop is estimated at 1,160 and 1,350 kg CO2 equivalent per ha for non-legumes and legumes, respectively. This implies that growing a legume cover crop has a higher climate change mitigation effect than a non-legume cover crop.

Table 1.2 Processes affecting climate change mitigation by legume or non-legume cover crops and estimated typical values (and range in parentheses) for radiative forcing in units of CO2 equivalents (CO2e). [5]

Process	CO2e (kg/ha/year) a)		Source of variation
	Non-legume	legume	
Soil C sequestration	1,170 (780, 1,560)	1,170 (780, 1,560)	Site to site variation, time cover cropping
Soil N2O efflux	-40 (10, -90)	-20 (30, -60)	Fertiliser N rate, incorporation
Reduced downstream N2O flux	30 (0, 220)	0 (0, 130)	Cover crop effect on N leaching
Reduced N fertiliser use			
Green manure credit	0	200 (80, 590)	Cover crop N fixation
Organic matter credit	40 (0, 200)	40 (0, 200)	Same as soil C sequestration
Soil CH4 flux	0	0	Too few studies for variation
Farm operation fuel use	-40 (-10, -100)	-40 (-10, -100)	Planting and termination choices
Total biogeochemical effect	1,160	1,350	

a) Positive values represent net mitigation of radiative forcing, while negative values represent sources of radiative forcing.

Source: Kaye and Quemada (2017), adapted by Wageningen Research.

The biggest effect of growing a cover crop is caused by soil C sequestration, assuming optimal crop and soil management. Both legumes and non-legumes also lead to a reduced N fertiliser use, partly because of the additional organic matter leading to N mineralisation in the next growing season, and partly, but only in the case of a legume, because of N fixation. Growing a cover crop can also have negative effects on climate change mitigation , e.g. when an additional tillage operation has to be carried out, requiring fuel (leading to CO2 emission) and leading to a soil N2O efflux. On the other hand, a cover crop also reduces the downstream N2O-flux.

1.4.3 Total climate change mitigation potential

The total climate change mitigation potential of CCC per NUTS2-region can be calculated as:

[5] Kaye and Quemada (2017) also describe a mitigation effect due to an albedo change. However, there is a large amount of uncertainty about this factor. Therefore, this factor has not been included in our calculations.

Mitigation $potential_r$ = Mitigation potential from N_r + Mitigation potential from C_r (1.1), with:

- Mitigation $potential_r$ = total climate change mitigation potential in region r, in kg CO2e/year;
- Mitigation potential from N_r = climate change mitigation concerning N in region r, in kg CO2e/year;
- Mitigation potential from C_r = climate change mitigation concerning C in region r, in kg CO2e/year.

Equation 1.1 expresses that there are two important processes, which make up for the total mitigation potential: 1) C-sequestration, resulting in higher soil organic matter contents, 2) reduction of N-losses, including a reduced need of N-fertiliser production:

1) Mitigation potential from C_r = area_c_r * f * m * biomass_r , in kg CO2e (1.2), with:

   - area_c_r = Acreage of a specific main crop c in region r, in ha;
   - f = conversion factor of biomass into soil organic matter, in kg SOM/kg biomass;
   - m = conversion factor of soil organic matter into climate change mitigation, in kg CO2e
   - biomass_r = biomass production of the CCC in region r, in kg per ha.

2) Mitigation potential from N_r =area_c_r * s * Nsurplus_c * rain_r (1.3), with:

   - area_c_r = Acreage of a specific main crop c in region r, in ha;
   - s = conversion factor from N-surplus into N-savings, including precipitation surplus;
   - Nsurplus_c = N surplus in crop residues and soil after harvest of main crop c, in kg/ha;
   - rain_r = Precipitation surplus in region r during a fallow period after a specific main crop, in mm.

In words: The mitigation potential concerning C of growing cover crops in a region can be calculated as the biomass production in the region and the conversion of that biomass into soil organic matter, leading to climate change mitigation. The mitigation potential concerning N of growing cover crops in a region can be calculated as the sum of the mitigation of the different main crops, which depends on the acreage of the different crops, their respective N surplus and the risk of leaching in periods of a precipitation surplus.

1.5 Scope and limitations of the study

This study focuses on the adoption of CCC in the EU-28 member States (MSs), although literature from outside the EU is taken into account. Eurostat gives annual overviews of main crops grown in the different MSs, but statistics on CCC are not available to the extent that would give a perfect overview. As a consequence, different data sources had to be combined and assumptions had to be made to be able to draw conclusions.

2 Data and methodology

2.1 Conceptual approach – decision tree

A conceptual approach was developed to organise focused data search. To this end, a decision tree was developed (Overview 2.1). The aim of the data search were:

- to provide material to give a clear insight in the current and potential adoption rates of CCCs, the estimated climate change mitigation potential and the management practices applied in CCCs;
- to make a well-based selection of case study regions possible based on this material. [6] The most important criteria for this selection were high adoption and climate change mitigation potentials, expressed in ha and kg CO2e/ha/year per region, respectively. The climate change mitigation potential [7] per NUTS2 region was calculated according equations 1.1 – 1.3 in 1.4.3.

The first step was to identify the 'big crops' in the EU. For a significant impact in terms of climate change mitigation, the crops or cropping systems to be considered need to have a significant acreage.

The second step was to identify where in the EU the adoption and climate change mitigation potentials are high. The opportunities to grow a CCC and the climate change mitigation impact of a CCC are not the same in every region and in every crop rotation. It was assumed that combine harvestable crops provide the best opportunities to grow a CCC. The mitigation potential depends on the amount of biomass produced by a CCC. This amount depends on a number of factors like species, moisture and nitrogen availabilities and the length of the growing period of the CCC. The estimation method for the climate change mitigation potential is elaborated on in 2.2.

The adoption potential depends on the adoption rate already reached but also on the length of time between two main crops and the availability of moisture in that period. To estimate the adoption potential of CCCs in a region, the acreages of a main crop in or after which a CCC can be sown, have been taken into account. In principle, any combine harvestable crop is suitable for growing a CCC. In practice, CCCs are mostly sown after or under cereals. Therefore, the total potential adoption was estimated as the acreage of cereals in a NUTS2 region minus the hectares of CCC that were already cultivated in that region in 2010 (the acreages of 'intermediate crops' according to the data of SAPM, 2010). To prevent double counting, only the cereals have been corrected in this way; this correction has not been applied for other big crop groups. [8]

Ranking

To identify the most attractive regions per crop group for selection in the survey, the total mitigation potential (in kton CO2 per year) per region was calculated as the product of the mitigation potential per ha (in kg CO2 per ha per year) and the adoption potential (in ha) per NUTS2–region per big crop type. The region with the highest total mitigation potential received the highest ranking score, which was used to identify the favourite regions. The NUTS2-regions with the highest score are presented as most suitable to select for the survey. Besides the crop group wise ranking a total ranking of all selected crop groups was carried out in the same way. This gives an indication of NUTS2 regions with the highest mitigation potentials over cropping plans.

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[6] To facilitate this selection and the following survey, carried out by interviewers in the regions selected, information was required at NUTS2-level when possible.

[7] Our calculation has only been applied for the C-sequestration, being the major of source of mitigation compared to the contribution of reducing N-losses and N-fertiliser input. This results in an underestimation of the mitigation potential, but that does not have much influence on ranking case study regions with a high potential.

[8] The SAPM-study did not provide data on the main crop in or after which the intermediary crops were grown. Therefore, the acreages of the intermediary crops were attributed to the most suitable crop group, the cereals. In the explanation of the ranking method it will appear that this choice does not influence the way in which different regions are evaluated for adoption potential.

This ranking method gives 'maximum mitigation potentials' . The rainfall during summertime (or in the early autumn in case of late crops) is decisive whether a CCC can be grown. Additional information on this topic was collected and presented as a map. The map can be used as a qualitative tool to potentially adapt the first selection of case study regions, checking whether a high adoption and/or a high mitigation can really be expected in the favourite regions.

The mitigation potentials in the second step focus on contribution of the C-sequestration, which is clearly dominant over the N-saving aspect of climate change mitigation (reduced downstream N2O flux and reduced N fertiliser use). In the third step, the N-aspect was focused on through identifying in which regions there is a risk of N-losses after harvest through a combination of high N-levels in the soil and in crop residues and precipitation surpluses in the period between two main crops. In principle, growing CCC is always worthwhile both from a farmer's perspective (soil quality) and a climate change mitigation perspective, not only when there is a risk of nitrogen losses in-between (main) crops. With good soil and crop management, a CCC is always useful for C-sequestration in the first place, since that process gives the highest mitigation effect (table 1.2). But the effect increases when high amounts of nitrogen are left behind in the soil and in crop residues after harvest of the main crop. Data on remaining nitrogen in soil and crop residues were not available, but average N-rates per region were. It is likely that in regions with high N-rates the risk for N-leaching is higher and especially a non-legume CCC will give a higher mitigation effect per ha.

The fourth step was to carry out a cost-benefit-analysis from the farmer's perspective in order to assess the economic attractiveness of growing a CCC.

The fifth and final step was to check whether legal obligations like the Greening Measures and other policies could contribute to adoption of CCC. The final result of these five steps is an overview of regions with a high climate change mitigation effect and practical and economic feasibility, allowing for high adoption rates.

2.2 Calculation of the climage change mitigation potential

Because data on regionally used varieties and biomass yields of CCCs were lacking, CCC yields and their mitigation potential had to be estimated. The climage mitigation potential was derived from Poeplau & Don (2015). Using data from 37 different sites they calculated an annual change rate of 320 ± 8 kg C/ha/year (1.4.1). The 37 sites mainly represented moderate climate regions; only a small number was located in tropical areas. Therefore, the value of 1,170 kg CO2e/ha/year was assumed to give an average figure for the EU as a whole. However, within the EU, there are big differences in growing conditions, not only leading to differences in main crop yields but also in CCC yields and, consequently, in mitigation potential per ha. These differences were taken into account through weighting the value of 1,170 kg CO2e/ha/year according to NUTS2-region on the basis of the average grain yield from cereals per ha per region, being 5.53 ton per ha (weighted average; source: Eurostat). Cereals are grown widely in almost all NUTS2 regions. Based on agronomic reasoning, we assumed that: [9]

1) the climate change mitigation potential is linearly correlated with the amount of biomass produced by the CCC. The more biomass is produced, the more C is sequestered and the more nitrogen is taken up by the CCC;
2) the amount of biomass of a CCC in a specific NUTS2 region is linearly correlated with the grain yield of cereals in that region, i.e. that factors like soil fertility and climatic factors have a similar effect on both main crops and CCCs. Under favourable growing conditions, cereals will show a high productivity. A CCC grown under the same conditions will therefor also be highly productive. The other way around is also valid;
3) the average value of 1,170 kg CO2e/ha/year correlates with an averae grain yield of cereals in the EU.

[9] Meta data on EU-level are not available to prove these assumptions. The agronomic reasoning applied can be found in different handbooks on crop production and in Smit (1996).

Overview 2.1 Steps in a decision tree on data collection for current and potential adoption of CCC:

1 Assess 'big crops' i.e. crops with large areas of main crops in the EU:
   a. Arable crops and other perennial crops including winter crops;
   b. Permanent crops, e.g. olives, citrus, grapes, other fruit species and permanent grassland.

Step 1 results into maps with the big crops in the EU (at NUTS1 and NUTS2-levels), after or under which a CCC could potentially be sown.

2 After step 1, assess:
   a. where in the EU the climate mitigation potential is relatively high;
   b. where in the EU the adoption rate is relatively low;
   c. where in the EU the potential adoption is relatively high, because under or after the main crops in these regions, a CCC has a high chance of success due to a) the opportunity to apply undersowing; b) sufficient time after the harvest of the main crop for a succesfull establishment of the CCC (is there an opportunity within the cropping plan?), and c) sufficient moisture after the harvest of the main crop for succesfull establishment of the CCC a).

Step 2 results into maps with scores on climate change mitigation and adoption potentials throughout the EU.

3 After step 2, assess:
   a. where in the EU relatively high amounts of nitrogen are applied, potentially resulting in high risks of N-leaching;
   b. where in the EU relatively high precipitation surplusses are observed, also potentially resulting in high risks of N-leaching;
   c. where the effect of growing a CCC is relatively big for its N-aspect, combining high N-rates and precipitation results.

Step 3 results in additional information compared to step 2, presenting the regions with a high potential loss of nitrogen due to leaching as a consequence of a precipitation surplus. Since the N-effect is relatively small compared to the C-effect of a CCC (table 1.2), this step is only helpful for finetuning the selection of case studies.

4 After step 3, assess whether the cultivation of CCC is feasible in these regions from the point of view of an attractive cost-benefit-balance; b)

   a. Costs refer to:
      i. Seeds;
      ii. Fuel for tillage and sowing;
      iii. Labour for tillage and sowing;
      iv. Possibly: herbicide to destroy the CCC before sowing/planting the following crop;
   b. Benefits:
      i. Climate mitigation; c)
      ii. Saving on N-rate in the following crop;
      iii. Yield increase of the following crop;
      iv. Increase of organic matter content of the soil. c)

Step 4 results in additional information compared to step 3, presenting the regions where the cost-benefit balance of growing a CCC is positive and adoption by farmers more likely.

5 After step 4, assess the overlap with legal obligations to grow CCC, e.g. to comply with the Greening Regulations and other policies; d)

Footnotes: See next page.

Footnotes:

a) In some main crops, CCC can be undersown. In that case, the availability of moisture after the harvest is less critical than with sowing after harvest of the main crop;
b) Costs and benefits largely depend on the species or mixture of species applied and the exact management activities applied. E.g. if a CCC is undersown in the main crop, relatively little effort is needed for cultivation, e.g. there is no need for tillage after harvest. If (long) cereal stubbles are considered as a CCC, left over after grain-stripping, no seeds need to be purchased and the field can add to give shelter and seeds to wild animals during winter time;
c) These factors are not easily expressed in euro per ha. For farmers, climate change mitigation is an 'external' benefit, normally not included in cost-benefit-calculations unless some form of monetary reward would be coupled to the climate mitigation 'service' of the farm to society (Cf. Greening for which a Greening premium is paid);
d) 70% of the arable land in the EU is subject to Greening obligations, and 5% of this area should be included in ecological focus areas (EFA's), corrected for the weighing factors (1, 0.3 and 0.7 for field strips, catch crops and N-fixing crops, respectively).

These assumptions were integrated in the estimation method in such a way, that the mitigation potential (in CO2e) is linearly higher in regions with higher than average gerain yields (due to favourable growing conditions) and linearly lower in regions with lower yields. In the calculations, the cereal grain yield per ha in the EU was set at a factor 100%. The average grain yield in the EU was coupled to the average mitigation potential of CCCs. An example of this calculation is given in table 2.1. The Netherlands has a higher cereal grain yield than average in the EU and, according to the assumptions made, a biomass production and, consequently, a climate change mitigation potential that is equally higher (i.e. with the same factor) than in the EU. For region X, having a lower than average cereal grain yield, the potential is lower than the figure of 1,170 kg CO2e/ha/year.

Table 2.1 (Virtual) example to clarify the climate change mitigation potential per region

Region	Cereal grain yield (ton/ha)	Yield factor (%)	Climate change mitigation potential (kg CO2e/ha)
EU	5.53	100	1,170
The Netherlands	8.0	145	1,693
Region X	3.0	54	635

Summarising, the total climate change mitigation potential per NUTS 2 region was calculated as:

Mitigation $potential_r$ = crop $acreage_r$ * yield $factor_r$ * standard mitigation potential (2.1), with:

- Mitigation $potential_r$ = total climate change mitigation potential of NUTS 2 region r (kg CO2e);
- Crop $acreage_r$ = total acreage of the big crops in region r under or after which a CCC can be sown (ha);
- Yield $factor_r$ = Average cereal grain yield in region r as a percentage of the average cereal grain yield in the EU;
- Standard mitigation potential = Standard value for climate change mitigation potential of 1,170 kg CO2e per ha as calculated by Kaye and Quemada (2017).

The value of 1,170 kg CO2e per ha is based on a non-legume cover crop sown under or after a main crop (see table 1.2). In case a legume cover crop is sown a higher mitigation potential per ha is expected (1,350 kg CO2e per ha) because of the cover crop N-fixation. This means that if all non-legume CCCs would be replaced by legume CCCs, the regional mitigation potential will increase by 15% at maximum. In practice, however, only a part of the CCC-acreage will consist of legume CCCs. Information about the distribution of non-legume and legume CCCs per NUTS2-region is not available, but it is plausible that a higher mitigation potential than given in our calculations is possible through growing legume CCCs. [10]

2.3 Data and information sources

An important data source for identifying areas of 'big crops' was Eurostat, which, however, does not hold information on CCC but only on main crops. The 'adoption of CCC' was subject of a specific survey by the EC (the co-called SAPM-study), in which cover crops on arable land were measured (defined as 'arable land covered with cover crop or intermediate crop') excluding harvested or grazed crops (Appendix 1). In the SAPM-study, the cover crops with grazing or haying were included under the 'winter crops'. A 'missing' category in the SAPM-database was the cover crop under/between permanent crops. This has to be taken into account when using these figures.

A number of data is presented at MS-, NUTS1 or, if possible, on NUTS2-level. [11] In calculations on mitigation and adoption potentials per NUTS1- or NUTS2-region, the exact acreage plays an important role, summing up the mitigation per ha over a region and the total acreage of crops where CCC could be an option. In specific cases, arable land is double counted when several crops are grown on the same fields throughout the year. In such cases, the adoption potential could be overestimated, i.e. when in all these crops on a specific field CCC could be implemented. E.g. growing vegetables could give such a risk. Since this study focuses on the big crops in the EU (see Chapter 3), the risk that double counting would occur, is very small, since these big crops are seldomly combined with other crops than CCC.

2.4 Agri-environmental zones

To determine in which regions of the EU, the adoption of cover crops has great potential reducing GHG emissions, it is essential to classify the participating EU countries in certain Farm Typology Zones. Farm Typology Zone (FTZ) units consist on the interplay of agri-environmental zones (AEZ) and farming systems (FT). Agri-environmental zones are derived from climate zonation of which in Europe 13 have been described by Metzger et al. (2005). Combined with the variables soil texture and terrain slope this climate zones form a diverse range of AEZ. The AEZ give some idea of the degree of risk of soil degradation and the potentials for cover crop uptake. Besides the biophysical qualities and variables of a landscape described in the AEZ, other factors determine the prevalence and success of a certain farm system in a specific country. A farm typology method has been developed by Andersen et al. (2007) to distinguish the main farm systems/types (FT) in Europe. It has four dimensions: specialisation, land use, farm size and farm intensity.

In chapter 3, our inventory and analysis focuses on the big crops throughout the EU. However, the question was not the if different big crops 'leave room' for CCC, but if different crop rotations do. The crop rotations applied in the different MSs were derived from the acreage data of all the crops per MS and from agronomic sources about most frequent crop rotations observed throughout the EU. In this way, the necessity to include detailed, explicit AEZs in our study was diminished, which would have taken a lot of time to assess and present.

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[10] In the case of a relatively high share of legume CCCs in certain regions, the estimation method underestimates the climate change mitigation in that region. However, this study focuses on regions with a high adoption potential, i.e. it is not yet clear whether farmers will decide to grow CCCs and if so, whether they will prefer legume or non-legume CCCs. In the calculations presented, another distribution factor between non-legume and legume CCCs will not influence the ranking between regions for mitigation potential.

[11] The NUTS classification refers to the classification of territorial units for statistics. This is a regional classification for the EU Member States providing a harmonised hierarchy of regions: the NUTS classification subdivides each Member State into regions at three different levels, covering NUTS 1, 2 and 3 from larger to smaller areas (http://ec.europa.eu/eurostat/web/regions/background).

3 Results

This chapter presents the steps that have been described in Overview 2.1- Steps in a decision tree on data collection for current and potential adoption of CCC.

3.1 'Big crops' in the EU

Step 1 is described in this section: Assess 'big crops' i.e. crops with large areas of main crops in the EU (Overview 3.1).

Overview 3.1 Step 1 - Assess 'big crops' i.e. crops with large areas of main crops in the EU:

a. Arable crops and other perennial crops including winter crops;
b. Permanent crops, e.g. olives, citrus, grapes, other fruit species and permanent grassland.

Step 1 results into maps with the big crops in the EU (at NUTS1 and NUTS2-levels), after or under which a CCC could potentially be sown.

Eurostat defines terms as used in the statistical sources like cereals, arable land, cover or intermediate crops etc. Some definitions relevant for this CCC study are given in appendix 1.

A first impression of the big crops in the EU is given in figure 3.1.

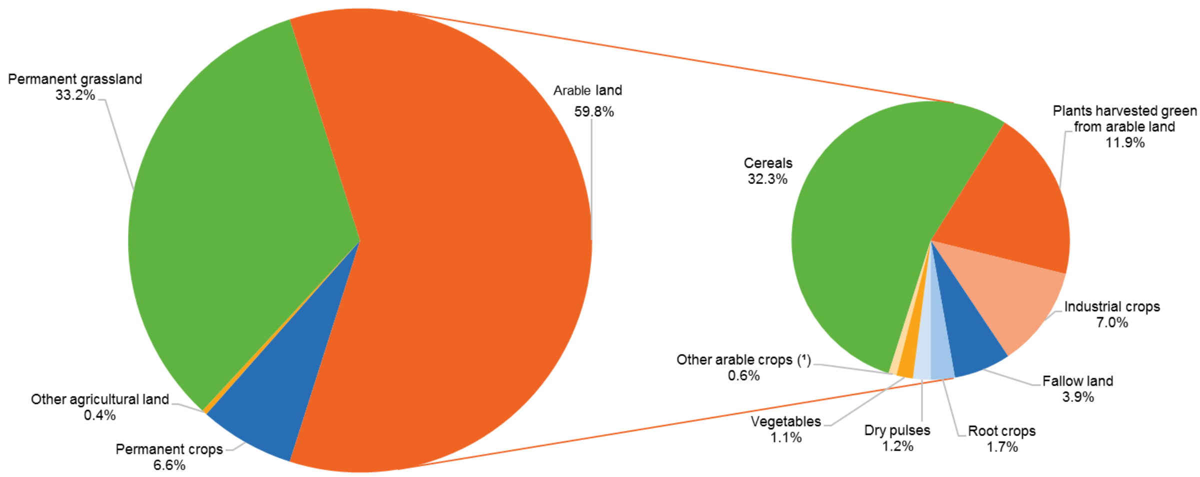


Figure 3.1 Shares of arable land, permanent grassland, permanent crops and other agricultural land use ('main areas') in the EU-28 in 2015 (% of total UAA) and shares of different arable crop groups within the share of arable land (these shares sum up to 59.8%, not to 100%). Note: the "main area" corresponds to the area of the land at the parcel; the land use linked to that area is the unique or main crop having occupied the parcel during the crop year. (¹) Includes flowers and ornamental plants, seeds and seedings and other arable land. Source: Eurostat.

Almost 60% of the total agricultural area in the EU consists of arable land and one third of permanent grassland. Permanent crops use 6.6% of the total area. In this study, the area of permanent grassland is not considered as a potential area of CCC-adoption, since the soil is not left bare in any season, at least when the grassland is managed properly (see section 3.1.9). Permanent and arable crops are more interesting for this study. The main arable crop groups are cereals (32%), plants harvested green from arable land (mainly fodder crops; 12%) and industrial crops (7%).

Figure 3.2 gives the acreages of cereals, protein crops, oilseeds and green plants per MS. The sums of these acreages are especially large in Germany, Spain, France, Italy, Hungary, Poland, Romania and the United Kingdom.

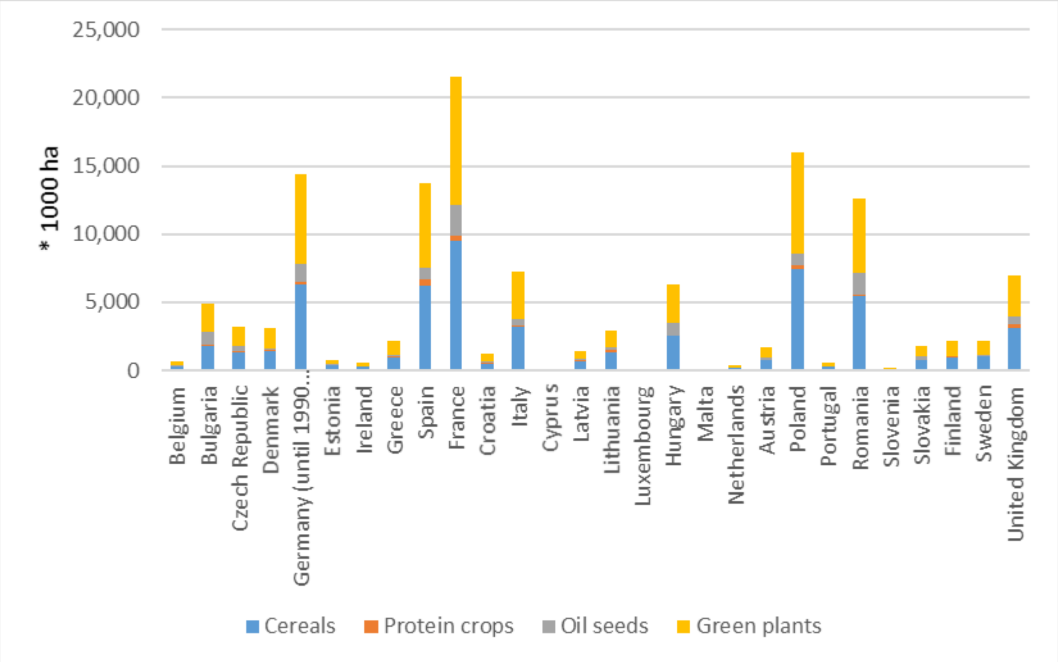


Figure 3.2: Area of cereals, protein crops, oil seeds and green plants per MS, EU-28, 2016 (*1000 ha). Source: Eurostat, processed by Wageningen Economic Research.

Table 3.1 presents an overview of the crop species per crop group. Within the group oil seeds, rape varieties are distinguished in winter and summer crops. Some big cereal species like wheat and barley have winter and summer varieties as well.

Table 3.1 Overview of crop species per crop group

Crop group	Crop species
Cereals	Wheat, spelt, rye, barley, mixtures, oats, grain maize, corn-cob-mix, triticale, sorghum, others wheats, rice
Protein crops	Field peas, broad and field beans, sweet lupins and other dry pulses and other protein crops
Oil seeds	Rape, turnip rape, sunflower seeds and soya
Plants harvested green from arable land	Temporary grasses and grazings, leguminous plants harvested green, Lucerne, other leguminous plants harvested green n.e.c., clover and mixtures, green maize, other cereals harvested green (excluding green maize), other plants harvested green from arable land

In the next sessions, the big arable crop groups and the permanent crops are presented in more detail.

3.1.1 Cereals

On average, 54% of the European arable land acreage counts cereals. France, Poland, Germany, Spain and Romania have the largest acreages of cereals (figure 3.3, map 3.1). Cereals are the biggest crop in the EU, in most MSs covering more than 40% of the arable land (up to 70% at maximum). Within this group, wheat and spelt and barley are the main players. In some MSs, there are significant acreages of rye and winter cereal mixtures, triticale, oats and maize (and sorghum). In the context of CCC, it is useful to discern between winter and spring cereals. Winter cereals cover the soil during winter time, but there can be a period of bare soil between the harvest of the winter cereal and the start of the next main crop. This period can be quite short when rape seed is sown after e.g. winter wheat but also quite long when the next main crop is a summer cereal, sugar beet or potato, leaving the soil bare during winter time. Undersowing a clover or a grass-clover-mixture after a winter cereal improves the C-sequestration. Growing CCC as an undersown crop in winter cereals is a good option, when the cereal crop is not too closed. Sometimes, a pre-harvest herbicide application is applied, but this can also shift to another phase in the crop rotation.

Both in winter and spring cereals, the harvest date is often early enough to grow a CCC. Cereals do not leave mineral N in the soil and N-losses from crop residues do not occur due to C-rich straw and stubble. A CCC needs a fertiliser dose and moisture for a successful start. However, undersowing with clover (or a clover-grass-mixture) is a good option if the crop is not too closed. A N-rich legume helps to mineralise the stubbles, enabling a lower or no N-fertiliser application for the CCC or the mineralisation of the stubble including straw when left at the field after harvest.

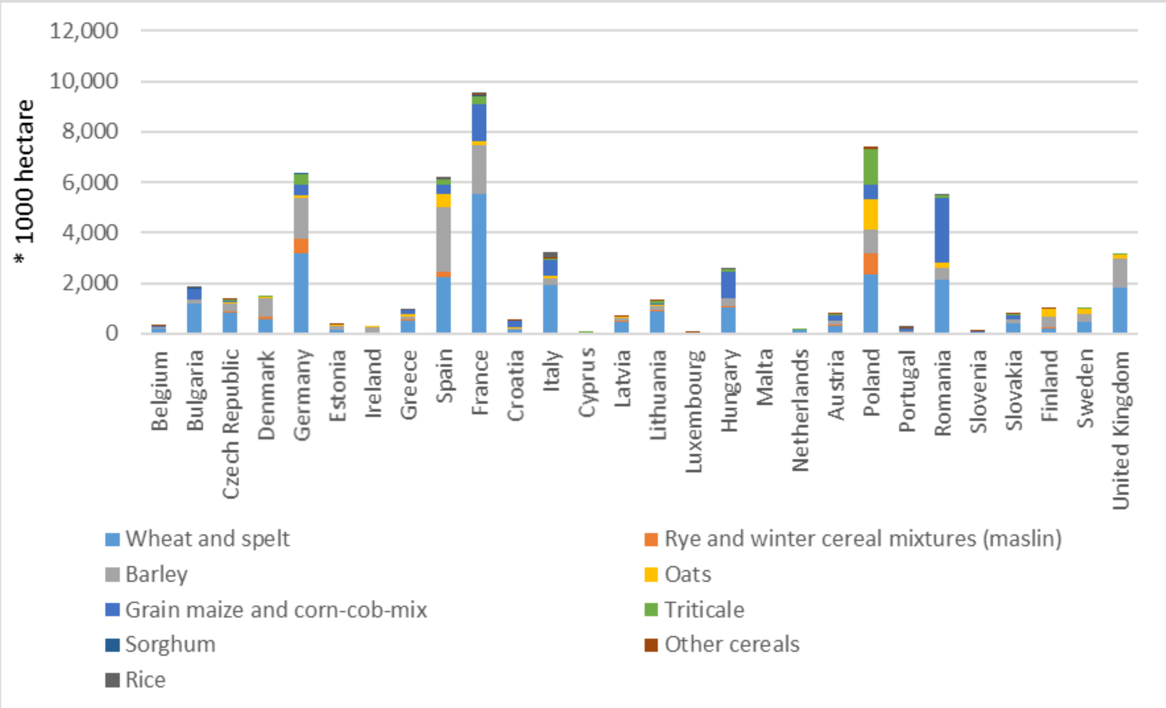
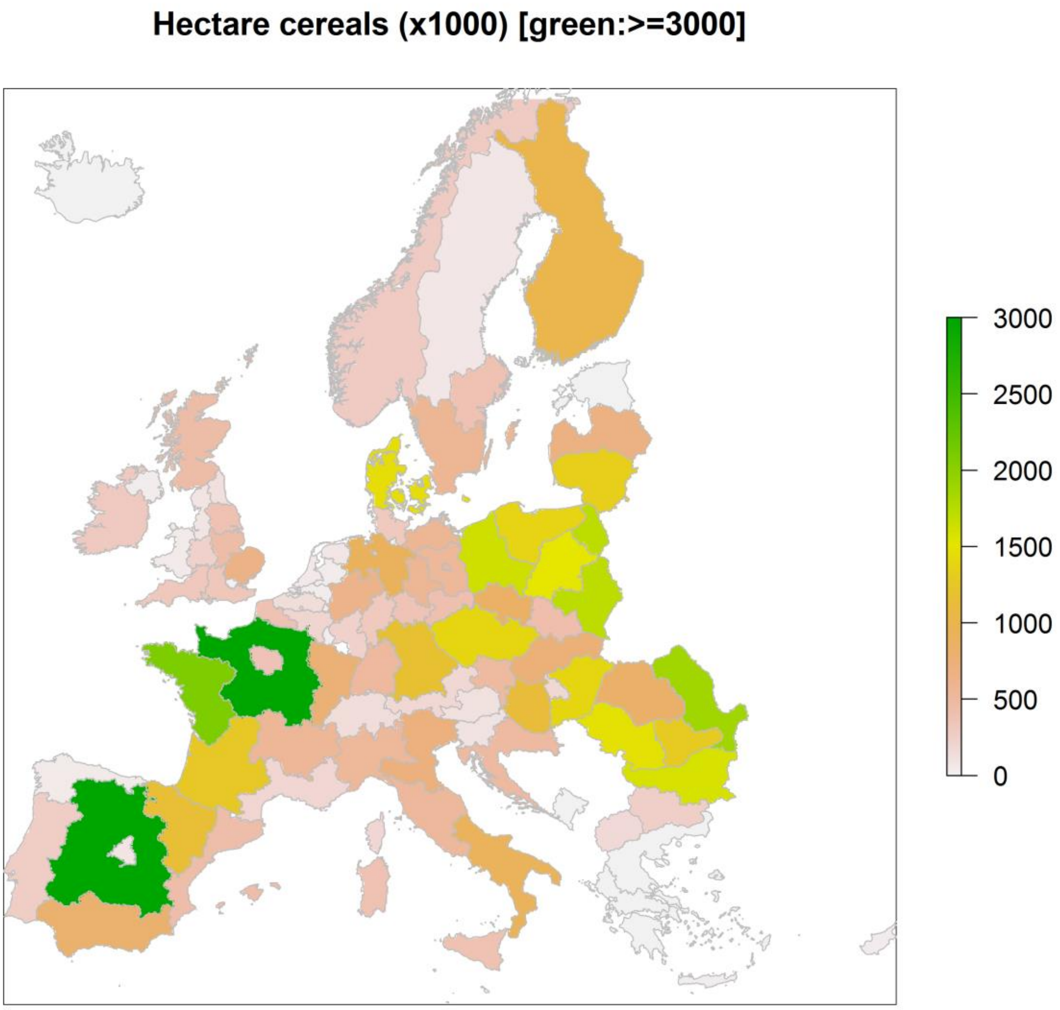


Figure 3.3 Acreage of cereals per MS, EU-28, 2016 (*1000 ha). Source Eurostat, processed by Wageningen Economic Research.

The acreages and shares of summer and winter cereals are presented in figure 3.4. The share of winter cereals ranges from 0% in Slovenia to 80% in Belgium. It is relatively high in MSs with relatively mild winters, e.g. Germany, France, United Kingdom, Belgium and the Netherlands. In MSs with hot summers (Italy, Spain, Greece and Portugal) or cold winters (Poland, Scandinavia, Hungary) have a higher share of summer cereals. During cold winters, cereals can freeze out. Regions with hot summers may not have sufficient water supply for rain-fed winter cereal growing. When the winter period and water supply allow, farmers would rather grow winter than summer cereals, since the yields of winter cereals are higher than of summer cereals, under normal conditions. Besides, winter cereals cover the soil during winter time, which is an advantage from the point of view of climate change mitigation .



Map 3.1 Cereal cultivation throughout the EU, presented on NUTS1 level. Source: Eurostat, processed by Wageningen Economic Research.

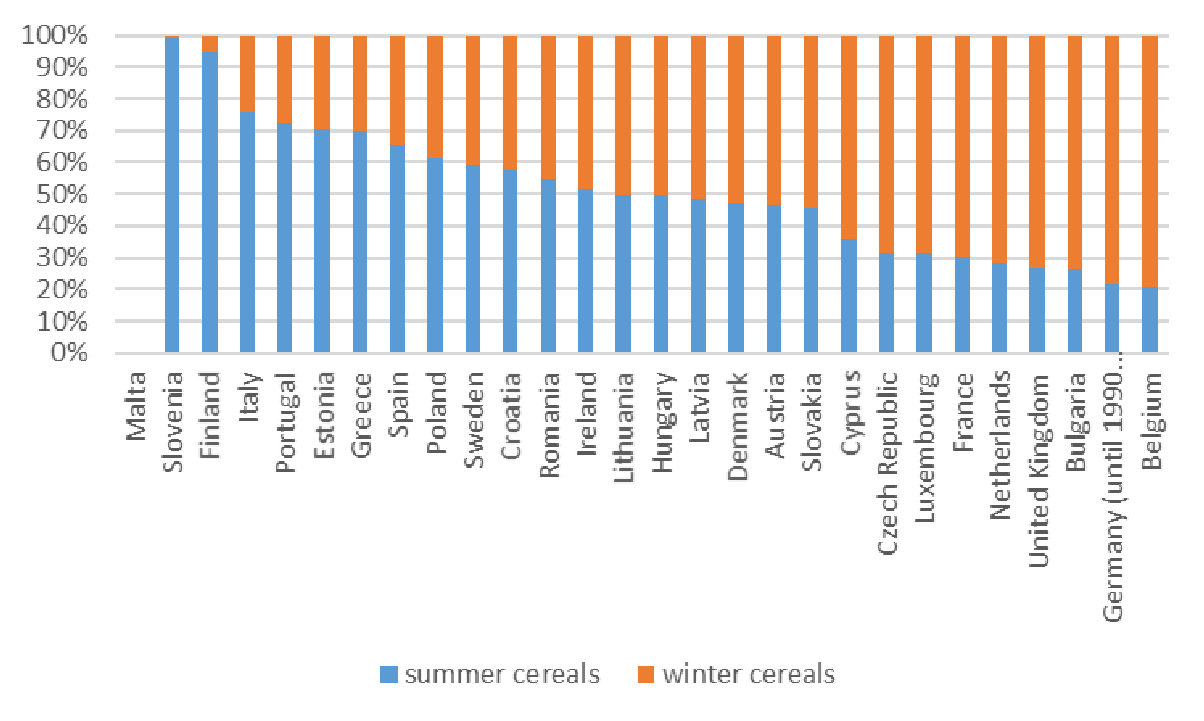


Figure 3.4 Average shares of winter and summer cereals per MS (2016, sorted by increasing share of winter cereals). Source Eurostat, processed by Wageningen Economic research.

3.1.2 Industrial crops

European farmers also grow considerable acreages of industrial crops, mainly oilseeds like rapeseed, besides cereals. Figure 3.5 presents the areas of oilseeds and other industrial crops per MS and map 3.2 per NUTS1 region. The most important MSs producing industrial crops are France, Romania and Germany. Within this group, there are differences with respect to the context of adoption potentials for CCC. Rapeseed is mainly a winter crop, but it is harvested early in the summer. Sunflower is a summer crop, but this crop is harvested late in the autumn, probably giving little room for a CCC during winter time.

89% of the acreage of industrial crops consists of oil seeds. Half of the oil seeds consists of rape and turnip rape, 39% of sunflowers and 8% of soya. 96% of the rape and turnip rape consists of winter rape and turnip rape. MSs growing most hectares of rapeseed are Germany, France and Poland. Important sunflower growing countries: Bulgaria, France, Romania and Spain. Italy grows the largest area of soya.

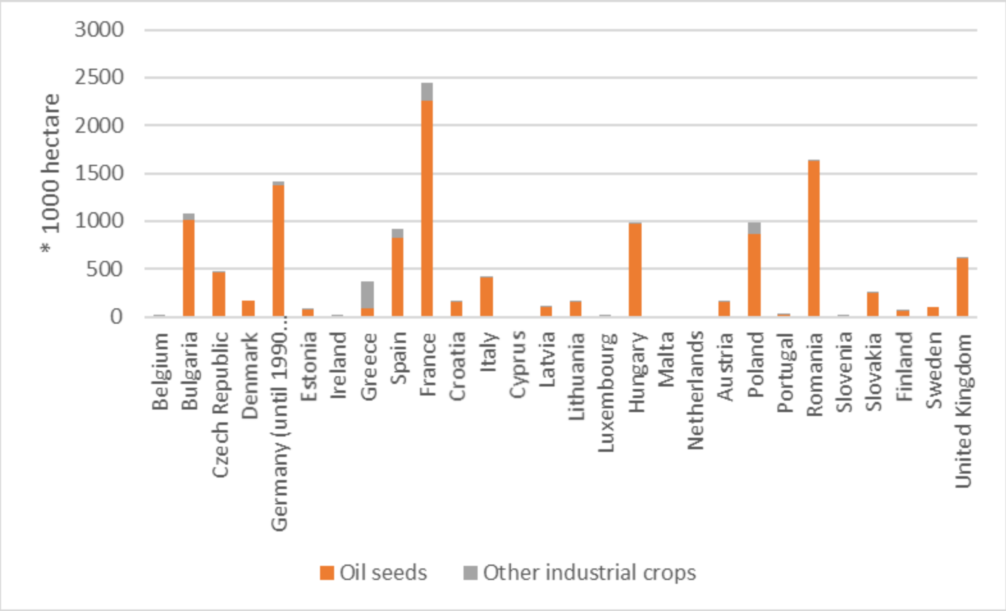
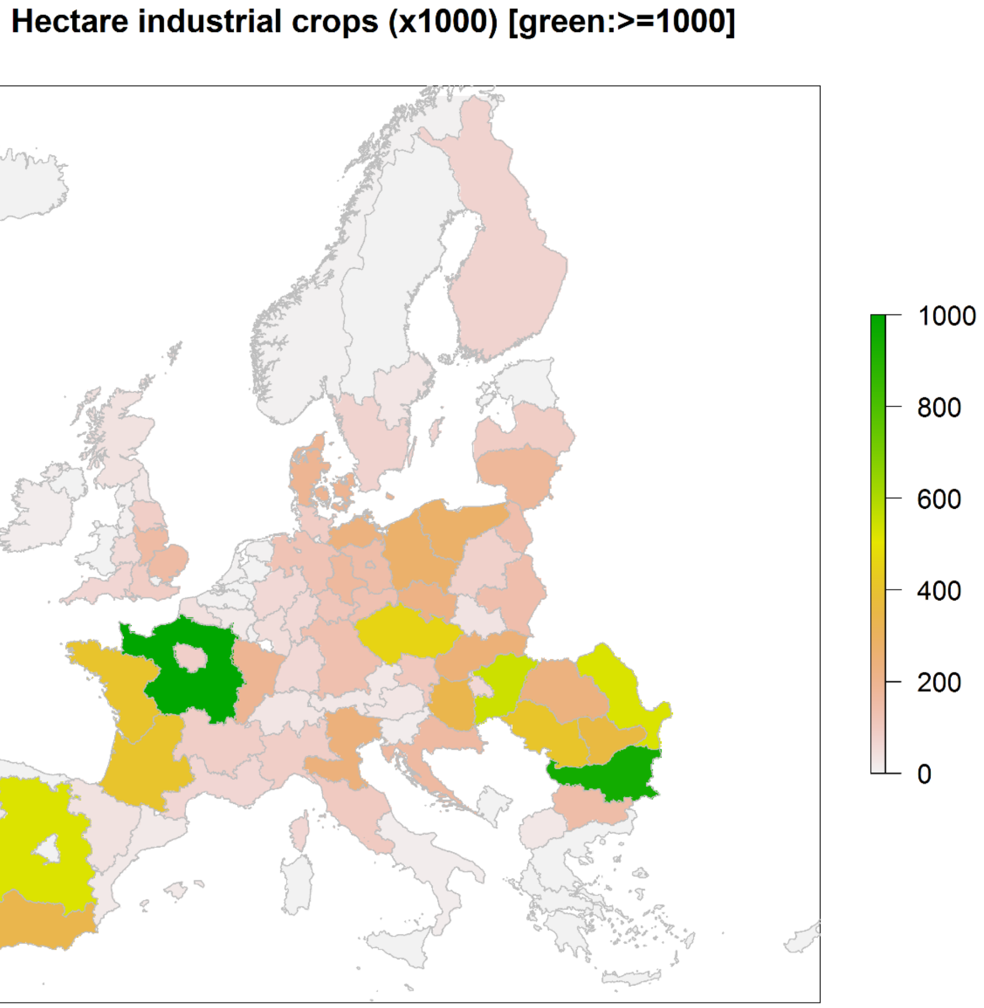


Figure 3.5 Acreage of industrial crops per MS (2016). Source: Eurostat, processed by Wageningen Economic Research.



Map 3.2 Cultivation of industrial crops throughout the EU, presented on NUTS1 level. Source: Eurostat, processed by Wageningen Economic Research.

3.1.3 Plants harvested green from arable land

In some countries, especially France, Germany and Italy, substantial acreages of arable land consist of green maize and other green harvested crops (mainly fodder crops; figure 3.6 and map 3.3). Temporary grasses and grazings made up for 43% of the acreage of green plants in the EU member states in 2016. The largest acreages of temporary grasses and grazings are observed in France, the United Kingdom, Sweden, Italy and Finland.

Green maize is the second most important green plant in the MSs: Germany, France and Poland grow substantial acreages of green maize. This includes green maize directly fed to livestock (without silage) and whole cobs (grain, rachis, husk) harvested for feedstuff or as silage for feed or for renewable energy production. They are grown in rotation with other crops, including (other) cereals, legumes and temporary grassland. In the Netherlands, growing CCC, either undersown or sown after harvest, is compulsory after green maize on sandy and löss soils (www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid/mest/vanggewas-na-mais), which is part of the national fertilisation regulations. [12] Green maize is often harvested late in the season, but the climate change (longer growing seasons) makes it increasingly feasible to grow a CCC successfully after this crop.

There are also leguminous plants harvested green like Lucerne. The highest acreages of these leguminous crops are found in Italy and Romania.

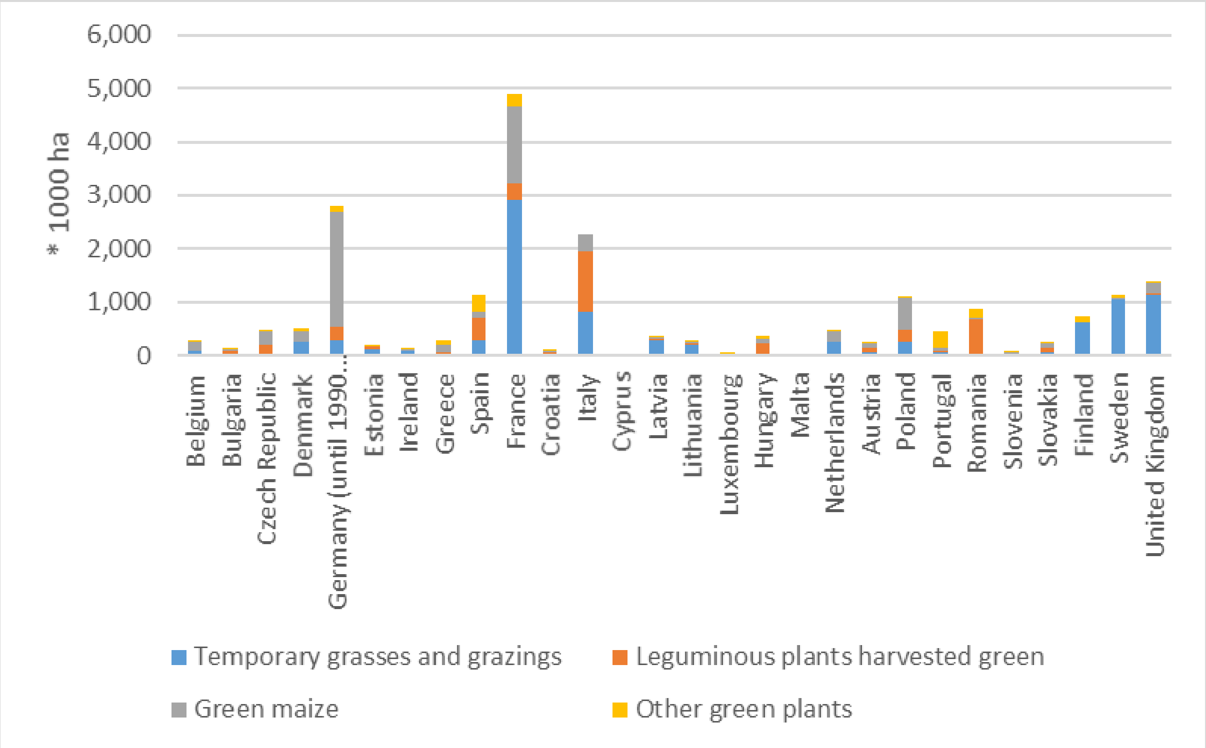
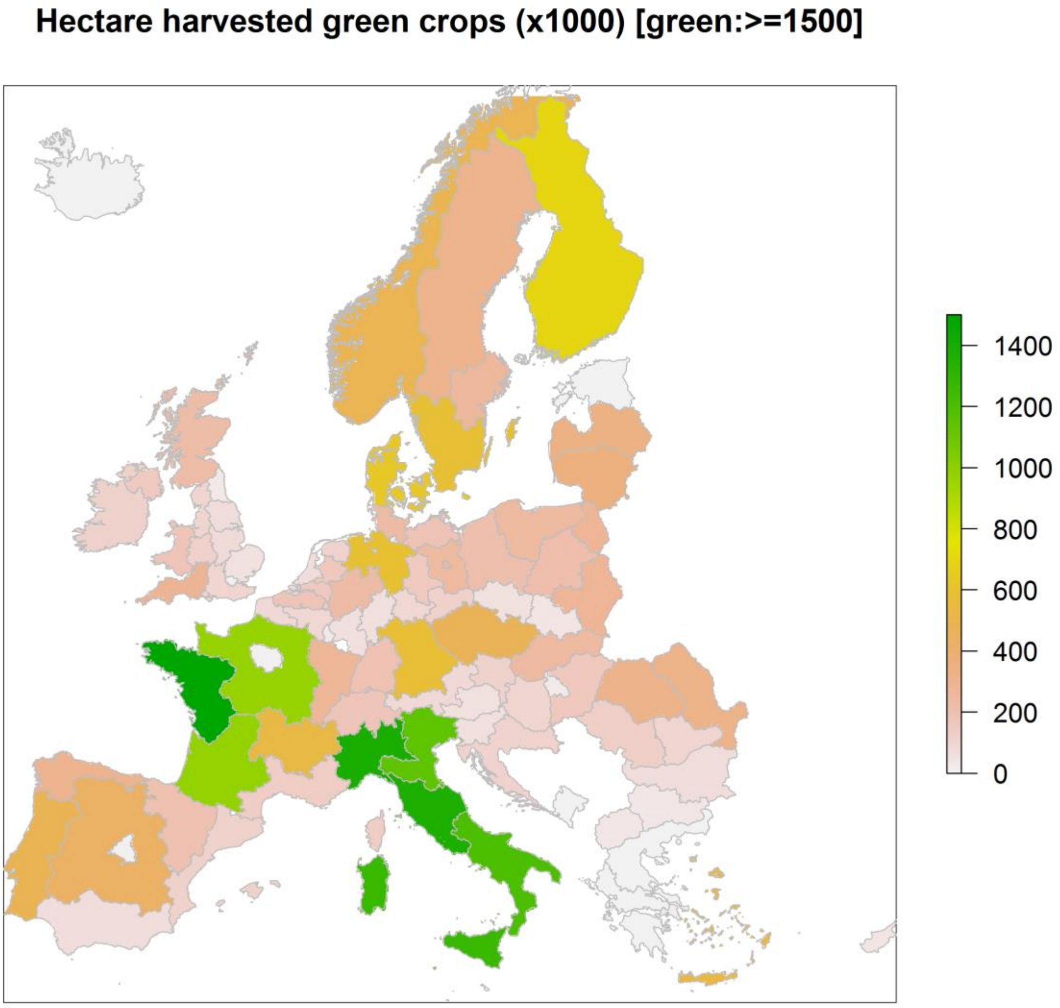


Figure 3.6 Plants harvested green from arable land per MS in 2016. Source: Eurostat, processed by Wageningen Economic research).

[12] The aim of this measure is reduction of nitrate leaching during autumn and winter. It is also advised in other MSs, like the EU, but not obligatory.



Map 3.3 Acreage of green harvested crops throughout the EU in 2013, presented on NUTS1 level. Source: Eurostat, processed by Wageningen Economic Research.

3.1.4 Dry pulses and protein crops for the production of grain

2% of the arable area in the EU consists of dry pulses and protein crops for the production of grain (including seed and mixtures of cereals and pulses). All these crop are nitrogen fixing. France, Poland, Germany, Spain and Romania have the largest areas of these crops, but never more than 10,000 ha (figure 3.7).

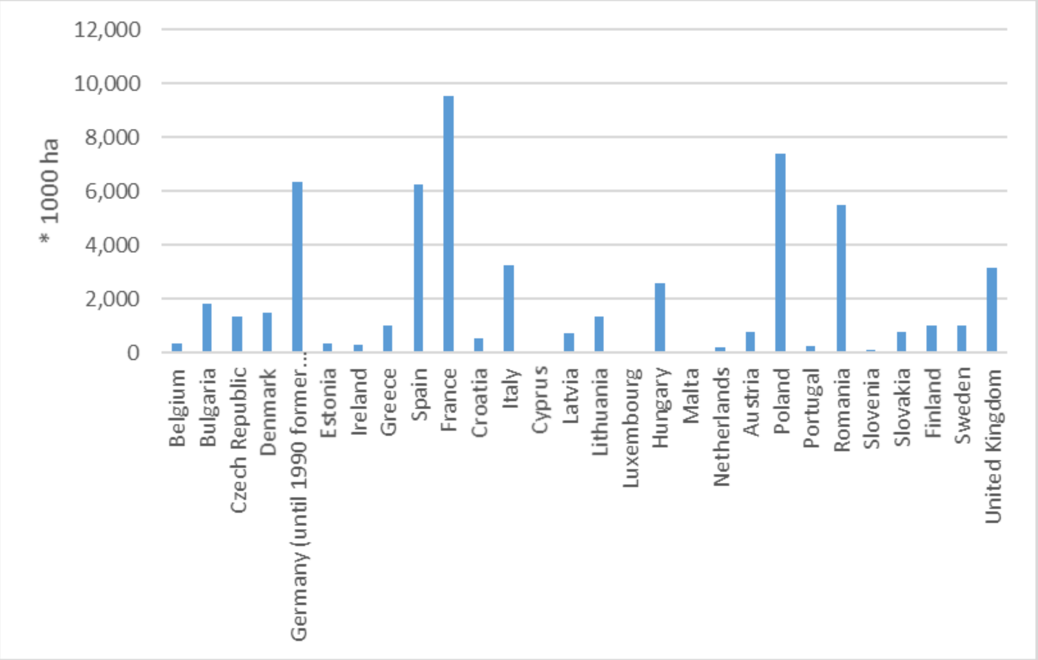


Figure 3.7 Acreage of dry pulses and protein crops per MS (2016). Source Eurostat, processed by Wageningen Economic Research.

3.1.5 Potatoes

Potato is known as a crop with high N-fertilisation rates and high amounts of nitrogen in the soil after harvest. The share of the European potato acreage is 1.6% of the total EU arable acreage (figure 3.8). Large areas of potatoes are grown in North West Europe (Belgium, UK, France, Germany, the Netherlands) and in Romania and Poland. In the Netherlands, growing CCC has become compulsory after potatoes due to the Nitrate Directive. Potatoes are often harvested late in the season, but the climate change (longer growing seasons) makes it increasingly feasible to grow a CCC successfully after this crop.

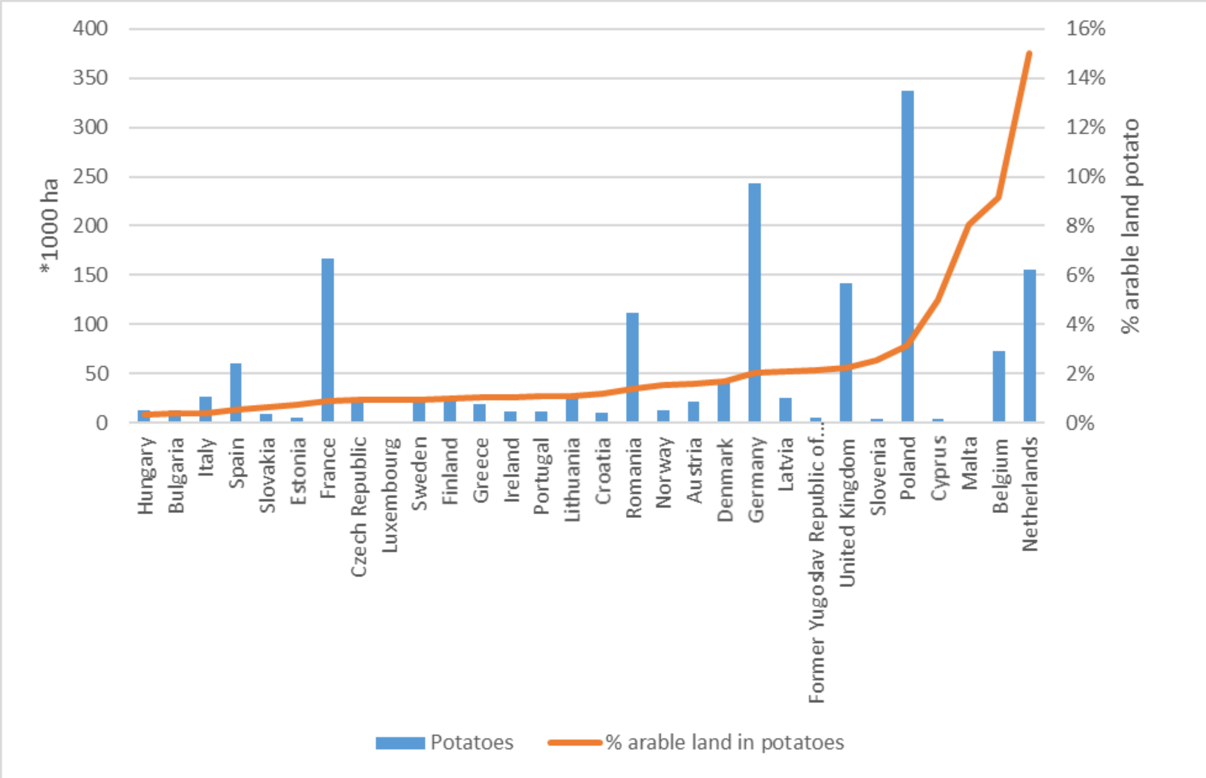


Figure 3.8 Acreage of potatoes and share of potato acreage in total arable land per MS (2013; acreage in 1,000 ha). Source: Eurostat, processed by Wageningen Economic researchs.

3.1.6 Sugar beet

1.6 % of the total EU acreage of arable land consists of sugar beet. Most sugar beets are grown in the same countries where potatoes are grown, i.e. mainly in Germany, France, Poland, UK and the Netherlands (figure 3.9). Sugar beets do not leave much nitrogen in the soil after harvest, but in modern times, the leaves are mostly left at the field, a potential source of nitrogen losses. Often, winter wheat is sown directly after harvest and this crop could take up the nitrogen that becomes available from the beet leaves.

Figure 3.10 presents the acreages and cropping shares of both sugar beet and potatoes. In MSs like Belgium and the Netherlands, these shares are relatively high. There is a long period before sowing or planting the crops, giving much opportunity to grow a CCC. On the other hand, on EU-scale, these crops are of less importance than the cereals, industrial crops and green crops.

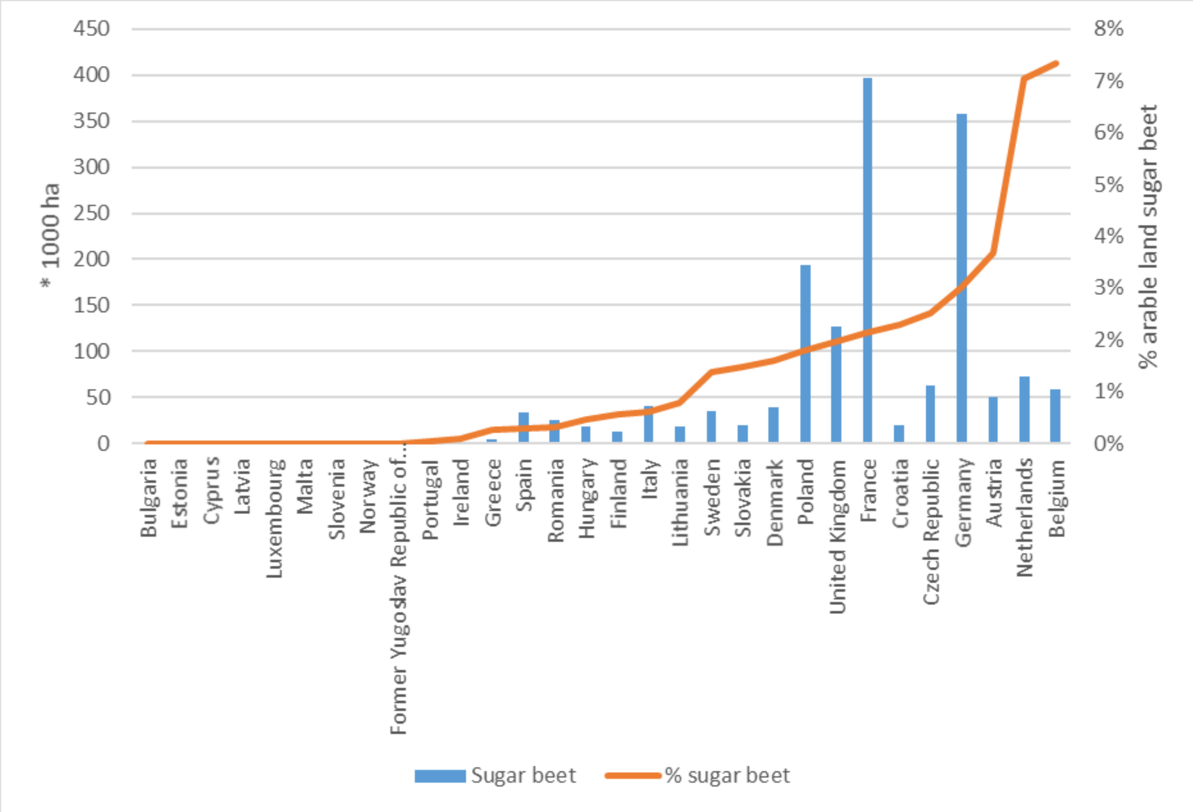


Figure 3.9 Acreage of sugar beet and share of sugar beet in acreage in total arable land per MS (2013; acreage in 1,000 ha). Source: Eurostat, processed by Wageningen Economic research.

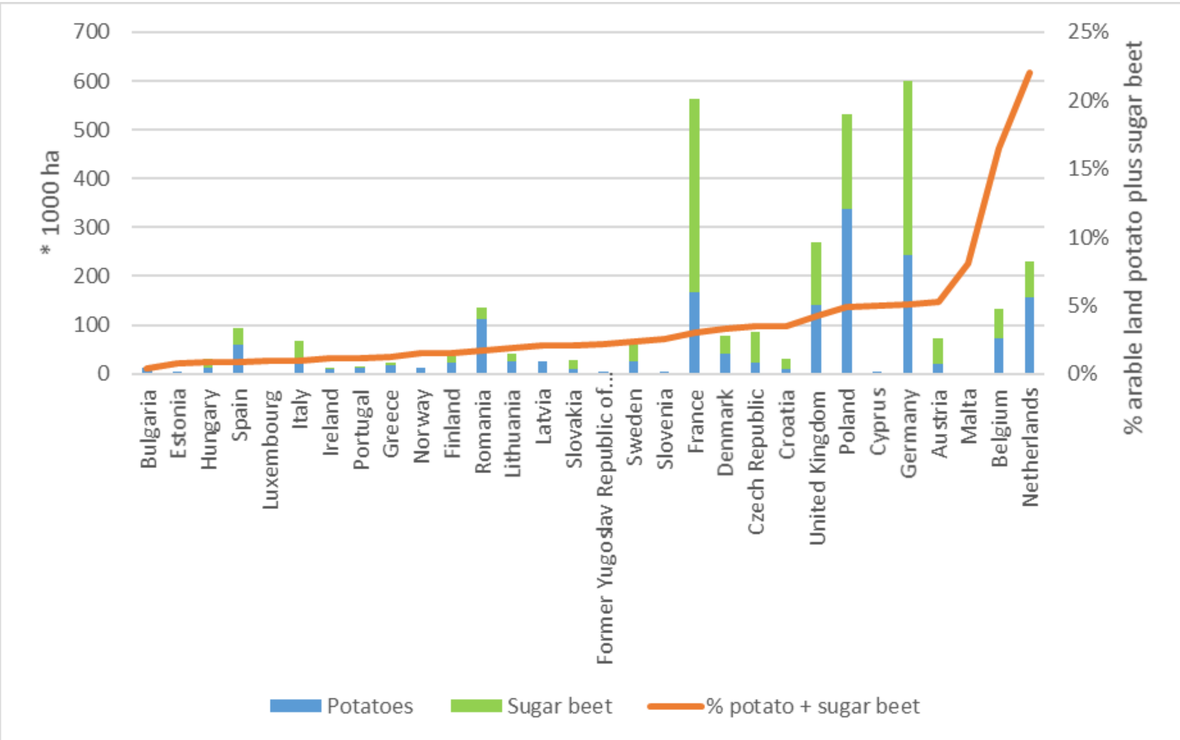


Figure 3.10 Acreage of sugar beet and potato and share of arable land as potato and sugar beet per MS (2013; *1000 ha). Source: Eurostat, processed by Wageningen Economic research

3.1.7 Permanent crops

3.1.7.1 Overview

Looking for opportunities of CCC under permanent crops some MSs are interesting when we focus on acreage (figure 3.10). Sizeable permanent crops are olives, vineyards (grapes), citrus and fruits and berries. Most important countries growing permanent crops are Spain, Italy, France, Greece, Portugal, Poland, Romania, Germany and Hungary. In orchards and vineyards (especially in organic farming) undersown CCC is known to suppress weeds and fungi. There is no data (yet?) about adoption of CCC under permanent crops, but the general observation is that in vine, apple and fruit orchards permanent crops (mainly grass) are grown in strips between the trees/shrubs. The crops in these strips fit into our definition of CCC. However, these strips are mostly permanent, not giving much opportunity to improve the adoption rate. In olive growing, often bare soil is observed under the trees. However, it is a question if under South European conditions growing CCC in olive yards is feasible because of lack of moisture (more information in the sections about olive growing). There is some evidence from a Portuguese study (Brito et al., 2015) that certain CCCs could be sown in relatively wet periods and add to the mulching layer. [13] In that case, the residues of the CCC could add to a decrease of evaporation losses. Another question is if there is much potential for climate change mitigation in such fields. In olive growing a N fertiliser rate of 200 kg/ha is applied and only 40-50 kg/ha is harvested (source), which would mean that there is a potential in olive growing, especially for periods of a precipitation surplus.

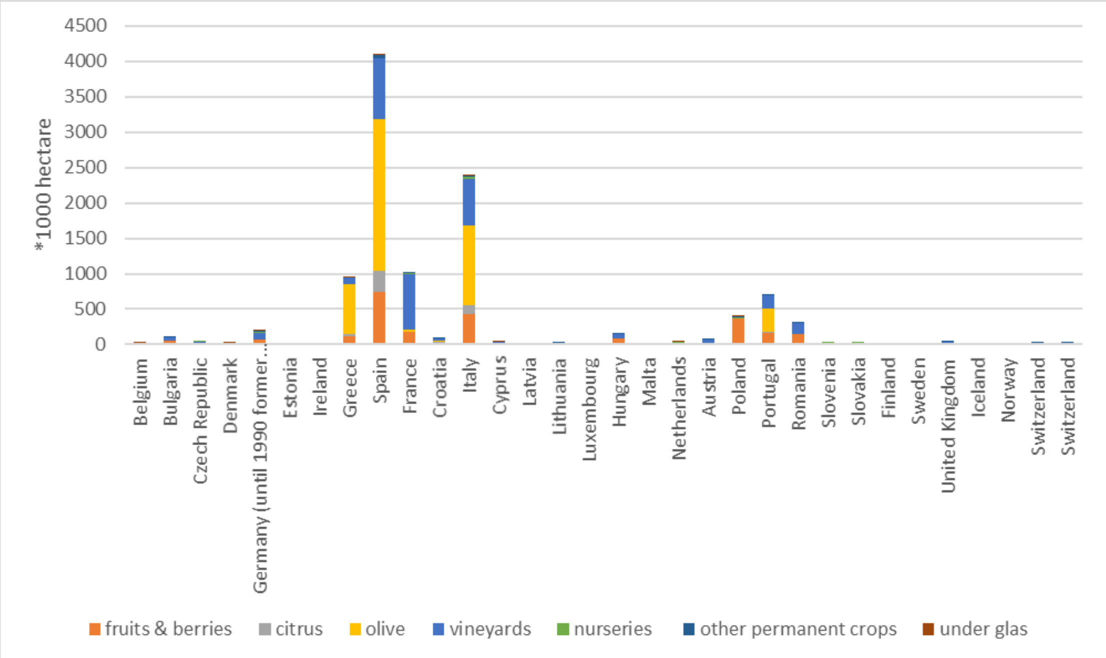


Figure 3.11 Acreage of a number of permanent crops per MS (2013; ha). Source: Eurostat, processed by Wageningen Economic research.

3.1.7.2 Olive cultivation and cover crop management

Olive trees are one of the most important crops in rain fed crop production in the Mediterranean region. Main European olive producing countries are Spain (a share in acreage of 65.6%), Italy (19.4%), Greece (9.5 %) and Portugal (4.8%) (Eurostat, 2016). Besides being of high economic value to these countries, olive production has an important social, cultural and environmental value, providing an important source of employment in rural areas hereby affecting the wellbeing of many families, creating a characteristic landscape and due to the immense territory also influencing the environmental qualities of the region. Many innovations have influenced this system in the last decades such as use of chemical fertilisers and pesticides, tillage between the rows and removal of vegetation cover and abandonment of grazing patterns. This has resulted in two main methods of cultivation, using traditional processes (non-irrigated) and modern processes (irrigation and mechanisation) (European Commission, 2012).

[13] A mulching layer can be built up with a cover crop and such a layer will reduce the evaporation losses (direct moisture loss to the air).

Inappropriate soil management practices (in both of the two current dominant systems) have created problems such as erosion and desertification (Milgroom et al., 2007). Soil erosion rates of 1.0 to 10.4 Mg/ha/year have been recorded and the high loss of soil is associated with declining soil organic carbon rates (Nieto, 2011) and removal of cover crops and/or weeds. There are opportunities for cover crops, in olive productions which are recognised in scientific literature: e.g. cover crops improve the water balance in the soil (Bowman and Billbrough, 2004), recycle nutrients in the soil (Weiner et al., 2002) and contribute to carbon sequestration (Repullo et al., 2012).

3.1.8 Permanent grassland

33.2% of the European main area is qualified as permanent grassland (see figure 3.1). Eurostat defines permanent grassland as 'land used permanently (for several - usually more than five - consecutive years):

- to grow herbaceous forage crops, through cultivation (sown) or naturally (self-seeded);
- not included in the crop rotation scheme on the agricultural holding.

Permanent grassland can be used for grazing by livestock or mown for hay, silage (stocking in a silo) or used for renewable energy production. Three different types of permanent grassland are identified in the EU Farm Structure Survey (FSS):

- 'pasture and meadow, excluding rough grazing: permanent pasture on good or medium quality soils, which can normally be used for intensive grazing;
- rough grazings: low-yielding permanent grassland, usually on low-quality soil (for example on hilly land and at high altitudes), usually unimproved by fertiliser, cultivation, reseeding or drainage, which can normally be used only for extensive grazing and are normally not mown or are mown in an extensive manner and which cannot support a large density of animals;
- permanent grassland no longer used for production purposes and eligible for the payment of subsidies which, in line with Regulation (EU) No 1306/2013 or, where applicable, the most recent legislation, are maintained in good agricultural and environmental condition and are eligible for financial support.'

Based on this definition, we must conclude that permanent grassland is not a (temporary) cover or catch crop. Pastures and meadows are grown for long-term commercial production purposes (intensive grazing), while rough grazings and permanent grassland are used for extensive production purposes and have a low N-leaching or mitigation risk because N-fertiliser use is not common nor economically attractive. The only exception is when permanent grassland is used as an undersown CCC under other permanent crops, like vine or apple.

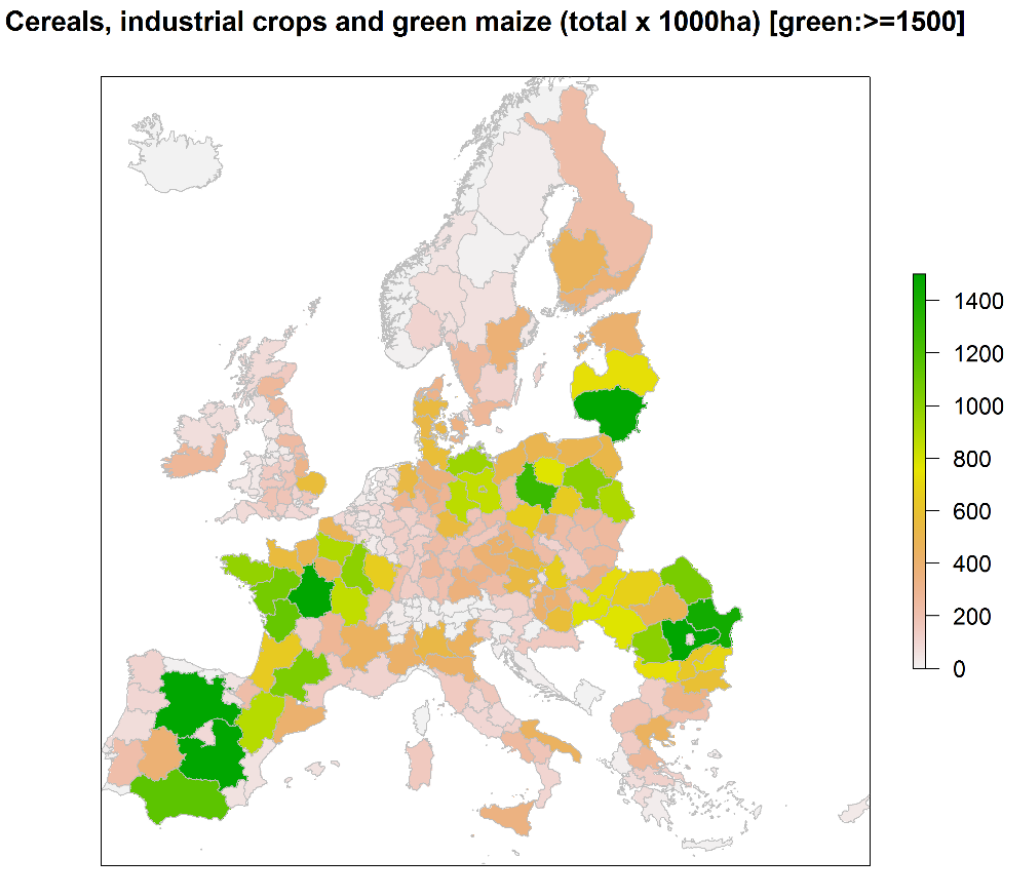
3.1.9 Concluding remarks

Cereals, oilseed and protein crops play an important role in EU agriculture and should be further explored for the potential of climate change mitigation through growing CCC. The total acreage of these three crop groups is given in map 3.4. Other crops like sugar beet and potato play a relatively small role in the EU, but farming systems with sugar beet – potato – cereals/green maize could be interesting to look at, which are mainly found in North Western Europe. The use of permanent cover crops under permanent crops is an issue of further discussion. The biggest permanent crop in the EU is olive.

Large arable regions in the EU have a cropping plan with winter wheat, winter barley and winter rapeseed. Figure 3.12 shows the total acreages of winter cereals [14] and winter rapeseed on MS-level. A number of MSs have high shares of these crops in the cropping plan, like Germany, Czech Republic,

[14] Besides winter wheat and winter barley, relatively small acreages of other winter cereals are included, like rye.

Bulgaria, France, United Kingdom and Poland (40 – 55%). In such cropping plans, the period between the harvest of these crops and the sowing of the next one is relatively short, varying from two to four months. However, in many cases a summer cover crop could add to C sequestration and N-savings. In cropping systems with more spring crops, a winter cover crop could be useful. The potential depends on the climatic conditions in the different regions, which will be presented in 3.2.



Map 3.4 Total acreage of cereals, industrial crops and green harvested plants throughout the EU in 2013, presented on NUTS1 level. Source: Eurostat, processed by Wageningen Economic Research.

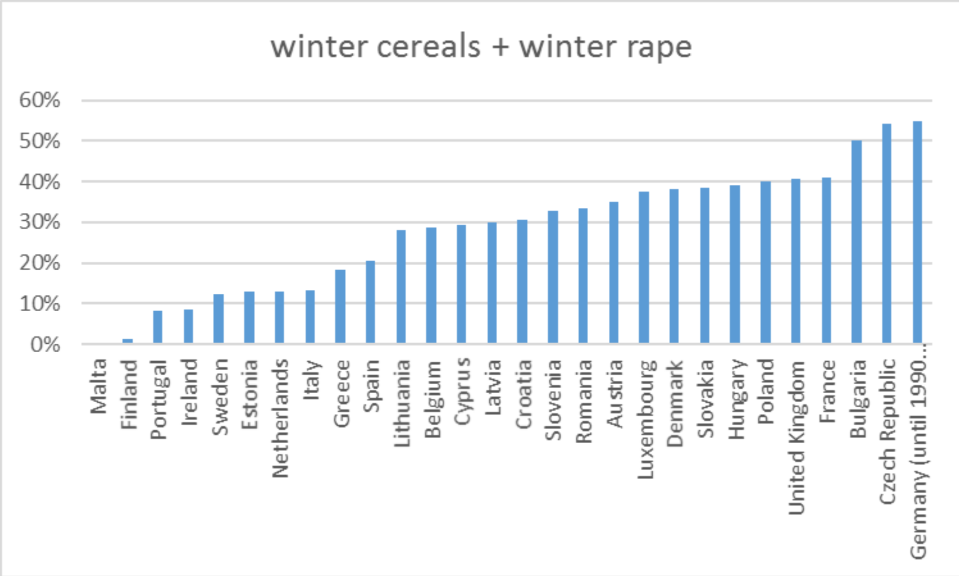


Figure 3.12 Acreage of winter cereals and rapeseed per MS (2013; % of arable land). Source: Eurostat, processed by Wageningen Economic research).

3.2 Climate change mitigation and adoption potentials thoughout the EU

Overview 3.2 presents the steps in this section and the results expected

<u>Overview 3.2 – Step 2:</u> After step 1, assess:

a. where in the EU the climate change mitigation potential is relatively high (3.2.1);
b. where in the EU the adoption rate is relatively low (3.2.2);
c. where in the EU the potential adoption is relatively high, because under or after the main crops in these regions, a CCC has a high chance of success due to a) the opportunity to apply undersowing; b) sufficient time after the harvest of the main crop for a succesfull establishment of the CCC (is there an opportunity within the cropping plan?), and c) sufficient moisture after the harvest of the main crop for succesfull establishment of the CCC (3.2.3) a).

Step 2 results into maps with scores on climate change mitigation and adoption potentials throughout the EU.

3.2.1 Climate change mitigation potentials thoughout the EU

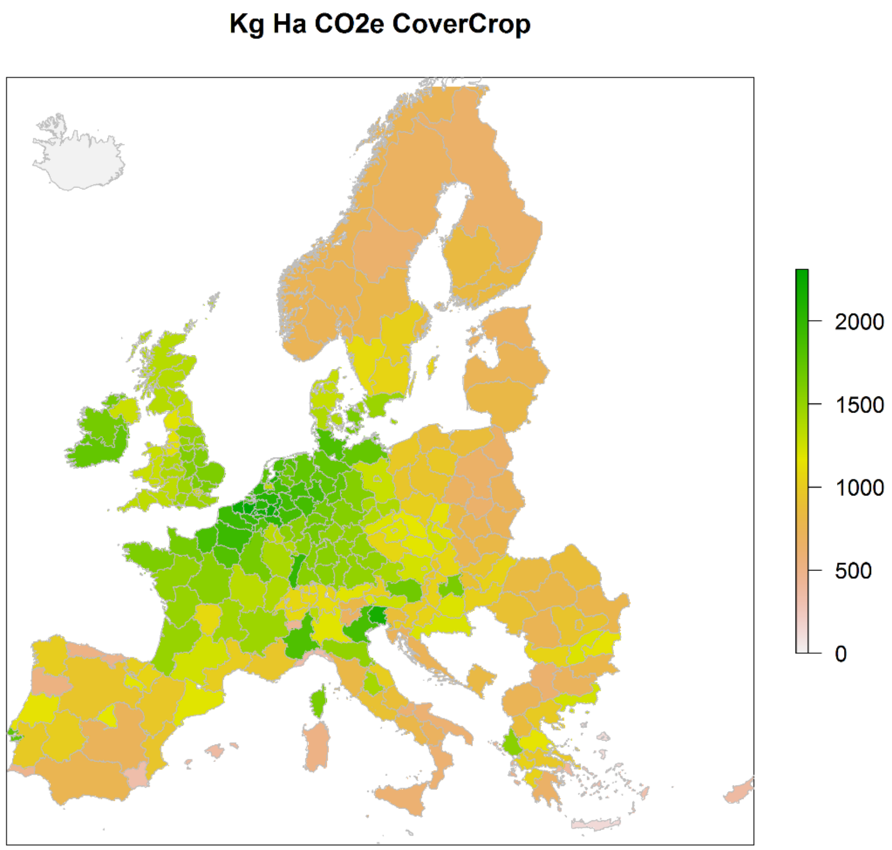
3.2.1.1 Mitigation potentials in arable crops

Combining grain yields and biomass production per NUTS2-region, the climate change mitigation potential had been calculated for the C-part, the C-sequestration process, which is dominant in the mitigation contribution of CCCs. Map 3.5 presents the climate change mitigation potential per ha. Big differences occur between North-western Europe and the drier/hotter and/or less fertile/colder regions in the Southern, Northern and Eastern parts of the EU. Due to the estimation method, this map presents in fact differences in grain yields per ha, but translated into climate change mitigation potentials, varying from 100 to 1,400 kg CO2e per ha. The differences between regions are very big. The total mitigation potential per region is calculated through multiplying the potentials per ha with the acreage of arable land in the regions.

3.2.1.2 Mitigation potentials in olives

Data on acreage of olives and other permanent crops were not available on NUTS2-level. Besides, due to completely different management practices and production patterns of these crops and potential CCCs, the method applied for arable crops could not be implemented in this case. Instead, a literature review was carried out for olives.

Rodriguez-Entrena (2012) evaluated several olive orchard management systems, and estimated the carbon sequestration potential of these management systems and their subsequent practices based on own elaboration and cited studies.Taking the Andalusian region as their study case 'only' 33% of the regions' surface area was covered with olive orchards, of which one third practised cover crop cultivation (MARM, 2009). The adoption of cover cropping can increase soil organic matter due to improved soil structure and incorporation of organic material. Under different management such as: Tillage or no tillage, burning or incorporating pruned materials, weedy cover crops or bare soil they show the carbon sequestration potential of the different practices. In the worst case, tillage with burnt pruning materials, no carbon was sequestered. Whilst a cover crop with burnt pruning material sequestered 1.47 t CO_2/ha/year and a cover crop with the incorporation of pruning material sequestered 3.85 t CO_2/ha/year. With current practices the olive growing area of Andalusia sequesters 2,188 kt CO_2/year. If all the farmers in the region adopt a cover crop with burnt pruning materials, the expected sequestration potential of the region increases to 2,278 kt CO_2/year (1,550 thousand ha * 1.47 t CO_2/ha/year; acreage from Rodriguez-Entrena (2012)).



Map 3.5 Climate change mitigation potential (kg CO_2e per ha). Source: own estimations based on grain yields of cereals from Eurostat (2013) and on Kaye and Quemada (2017; see table 1.2), assuming application of non-legume CCCs.

3.2.2 Adoption potentials throughout the EU

3.2.2.1 Adoption in 2010

In 2010, the EU monitored soil conservation [15] through a survey, the so-called SAPM-study [16]. This survey contains figures of number of farms and areas by size of arable area and cover crops per NUTS 2 region. Based on these data, figure 3.13 shows the share of intermediate cover crops as a percentage of arable land per member state.

The cover crop share between member states varies between 0% and 45% (share of total acreage of arable land). [17] Mountainous countries like Switzerland and Austria, who have to deal with soil erosion risks, show high percentages of cover crops (>20%). Countries in North West Europe (e.g. Belgium, Netherlands, France) have 10-20%, while the greatest part of the MSs scores between 0% and 5%. A few countries did not grow any intermediate crop. The available figures form a snapshot, the survey has been repeated in 2016 but the figures of this study are not available at the moment of this research. Moreover the share of cover crops under permanent crops is not included in the survey.

To estimate the potential acreage for growing a CCC the acreage of bare soil and of land with plant residues come into consideration. In principle it is possible to grow cover crops on these soils but is unclear which part of the acreage is suitable for a successful cover crop. Figure 3.14 shows the share of arable acreage (%bare soil and %plant residues) per member state, which could be available for growing cover crops in 2010. A quarter of the total area of arable land (105 million ha) in 2010 was left bare during winter time (table 3.2). Almost 10% was left with crop residues and almost 6% held a CCC.

In various member states the share of bare soil varies between 40% and 50% while these countries barely grow cover crops (e.g. Bulgaria, Hungary and Croatia). There are also countries with a significant proportion of acreage plant residues (e.g. Portugal, Ireland). The conclusion is that there is more room for growing intermediate cover crops in all member states. In most countries already growing cover crops, the possibilities for cover crops seem more limited than in member states who hardly grow cover crops. It should be noted that changes took place between 2010 and now, e.g. the introduction of the Greening Regulation, stimulating growing CCC. The room for the acreage of cover crops sown under permanent crops is not included in this data.

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[15] Soil conservation is generally accomplished with a variety of management techniques aimed at preserving the soil. Some of these including managing surface runoff, protecting exposed soil and protecting downstream watercourses from pollution and sedimentation. Soil loss and loss of soil fertility can be traced back to a number of causes including over-use, erosion, salinisation and chemical contamination. Soil conservation can ensure that soil is its most productive for the food supply and ensures that the habitats of area wildlife are maintained while protecting water from pollution (Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_cover; see also the following footnote).

[16] The Survey on agricultural production methods, abbreviated as SAPM, is a once-only survey carried out in 2010 to collect data at farm level on agri-environmental measures. European Union (EU) Member States could choose whether to carry out the SAPM as a sample survey or as a census survey. Data were collected on tillage methods, soil conservation, landscape features, animal grazing, animal housing, manure application, manure storage and treatment facilities and irrigation (http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Survey_on_agricultural_production_methods_(SAPM)). Soil cover and tillage practises were part of the survey. Respondents were asked to provide data on the area of arable land under soil cover and subject to various tillage practices. Both using less intrusive tillage and maintaining a soil cover during winter are two important practices that reduce soil degradation and help to prevent nutrient and pesticide runoff.

Data were collected on:
- arable land covered with normal winter crop,
- arable land covered with cover crop or intermediate crop,
- arable land covered with plant residues,
- arable land with bare soil.

[17] See Appendix 1 for more information on CCC's

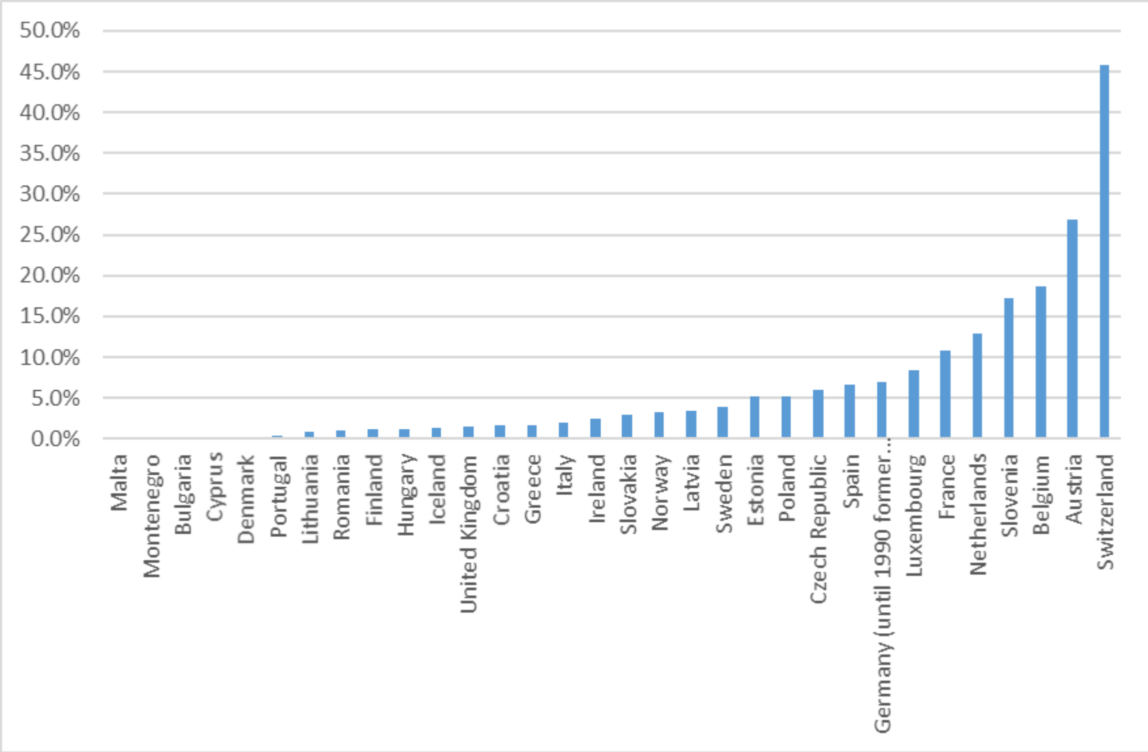


Figure 3.13. Cover or intermediate crops as a percentage of arable land per MS in 2010. Source: Eurostat, processed by Wageningen Economic Research.

Table 3.2. Acreage of arable land, intermediate cover crops (CCC), bare soil and plant residues (total EU, ha).

Variable	**Acreage (million hectare)**	**Percentage of arable land (%)**
Arable land	105	100
Intermediate cover crops	5.9	5.6
Bare soil	26.5	25.2
Plant residues	9.4	8.9

Source: Eurostat, 2010, processed by Wageningen Economic Research

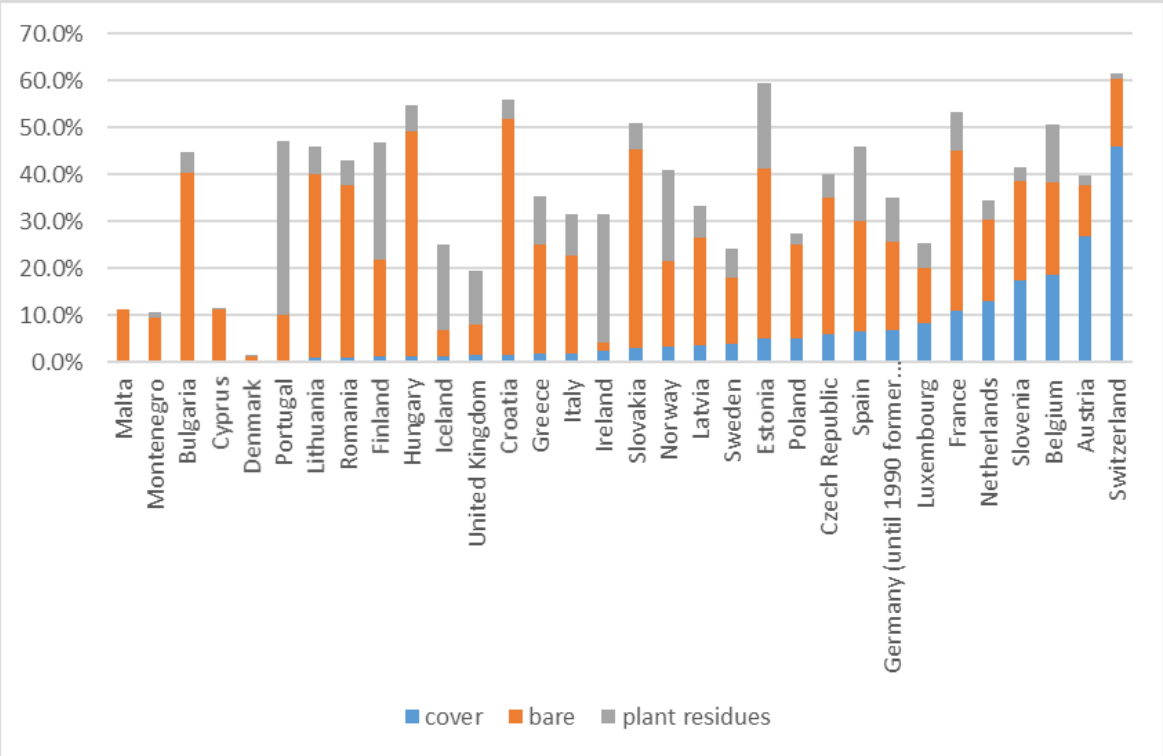


Figure 3.14 Acreage cover or intermediate crops, bare soil and plant residues as percentage of arable land per MS in 2010. Source: Eurostat, processed by Wageningen Economic Research.

Holdings and acreage

Adoption of cover crops in a region can be measured as the acreage of CCC divided by the total arable acreage in that region. Besides that it is also interesting to know how many farmers or holdings have adopted cover crops already. An indicator is the number of holdings (farms) growing CCCs as a percentage of the holdings that grow arable crops. This gives an impression of the share of holdings having more or less experience with cover crops. Figure 3.15 indicates the adoption rates per member state in 2010. The blue lines represent the number of farms that grow CCCs per MS compared to the total number of arable farms in that MS. In Denmark, Germany, Poland, Luxembourg and Malta more than half of the arable farms already grew a CCC. The orange lines represent the acreage of CCCs in the different MSs compared to the total arable acreage. In most MSs less than 20% of the arable land was covered with a CCC. Only in Austria (and non-MS Switzerland) had more than a quarter of the arable land with a CCC.

In Belgium, in 2010, 37% of the holdings had experience with growing cover crops. 19% of the acreage of arable land in Belgium was planted with winter cover crops or intermediate crops. In Germany 59% of the holdings grew cover crops, but only 7% of the acreage was covered by cover crops. This means that quite a lot of German arable farmers have experience with cover crops with relatively small areas per farm on average. In Switzerland, 39% of the holdings grew cover crops, which is less than in Germany, but 46% of the arable acreage was involved. This implies that the CCC area per farm in Switzerland was relatively large. In all other member states, the share of holdings growing cover crops was larger than the share of cover crop acreage. At EU level, 29% of the holdings with arable land had experience with growing cover crops. They cultivated 6% of the arable acreage with cover crops (SAPM, 2010).

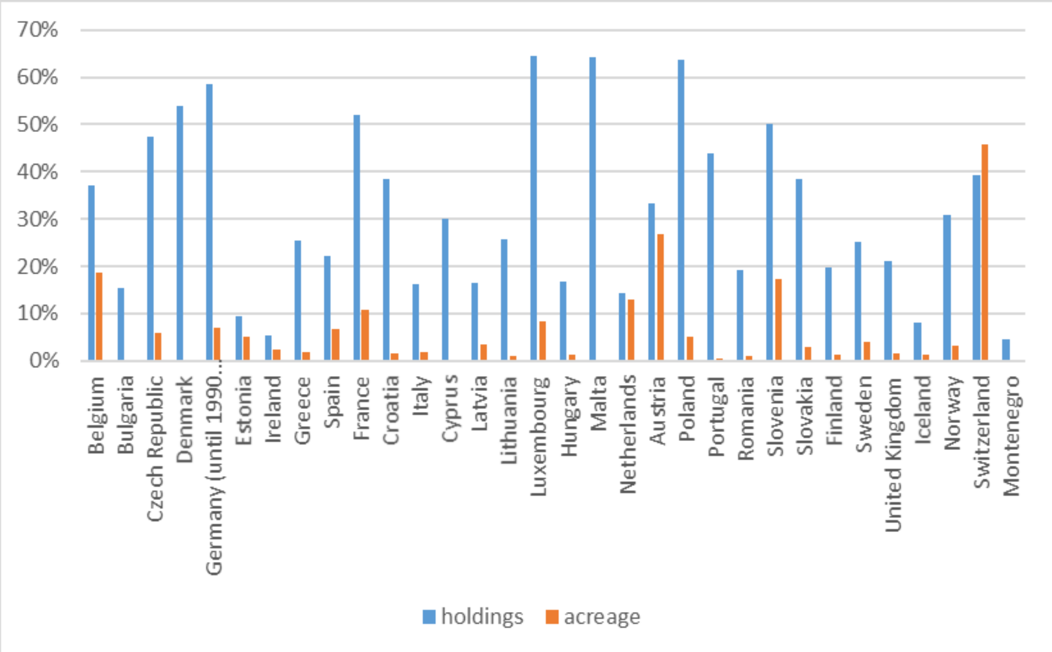


Figure 3.15 Adoption of cover crops: share of arable acreage planted with cover crops and share of holdings with arable land growing cover crops. Source: Eurostat SAPM (2010), processed by Wageningen Economic Research.

Conclusions:

- In 2010, less than one third of the farms in the EU grew cover crops;
- In that year, only a limited share of the total arable acreage was grown with cover crops;
- There are remarkable differences in the share of farmers and of acreages with CCC between member states (figure 3.15).

It is logical that never all land is cultivated with CCC because there are restrictive factors such as winter crops or natural disturbances (like extreme weather after the harvest of the main crop).

3.2.2.2 Adoption of CCC in more recent years

German statistics 2015/2016 indicate an more recent adoption rate (figure 3.16). All German arable farmers grew cover crops in that year, which is a great increase compared to 2010 (3.2.2.1). In 2015/16 22% of the German arable land (1.7 million of 7.8 million ha arable land) was sown with intermediate or cover crops (4% summer crop and 18% winter crop). Focussing on the winter cover crops: the largest part (91%) was used as green manure, 6% for fodder and 3% as biomass for energy. In 2007, German farmers grew 880,000 ha intermediate or cover crops (Destatis, 2008). This information shows that adoption rates can change over time, which has to be taken into account when selecting case study-regions.

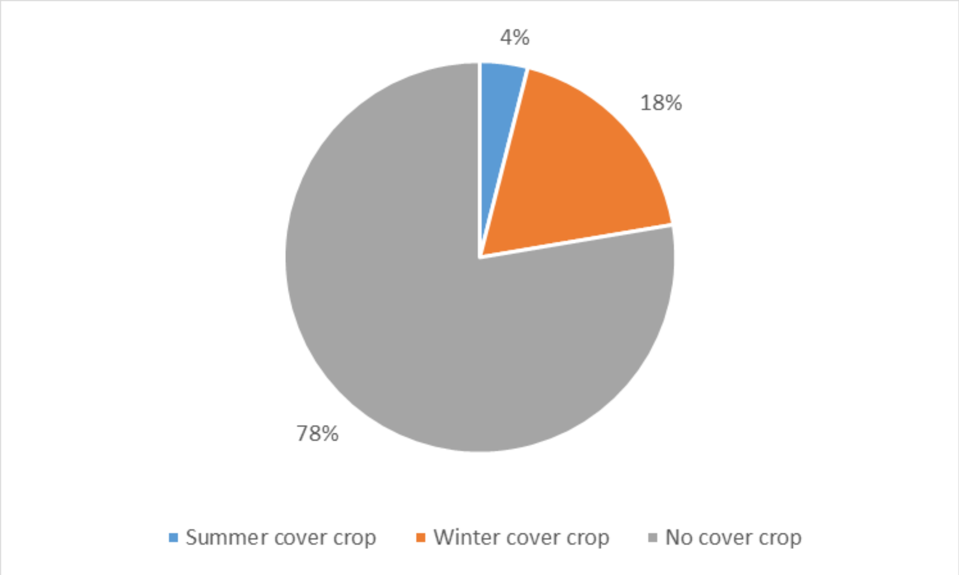
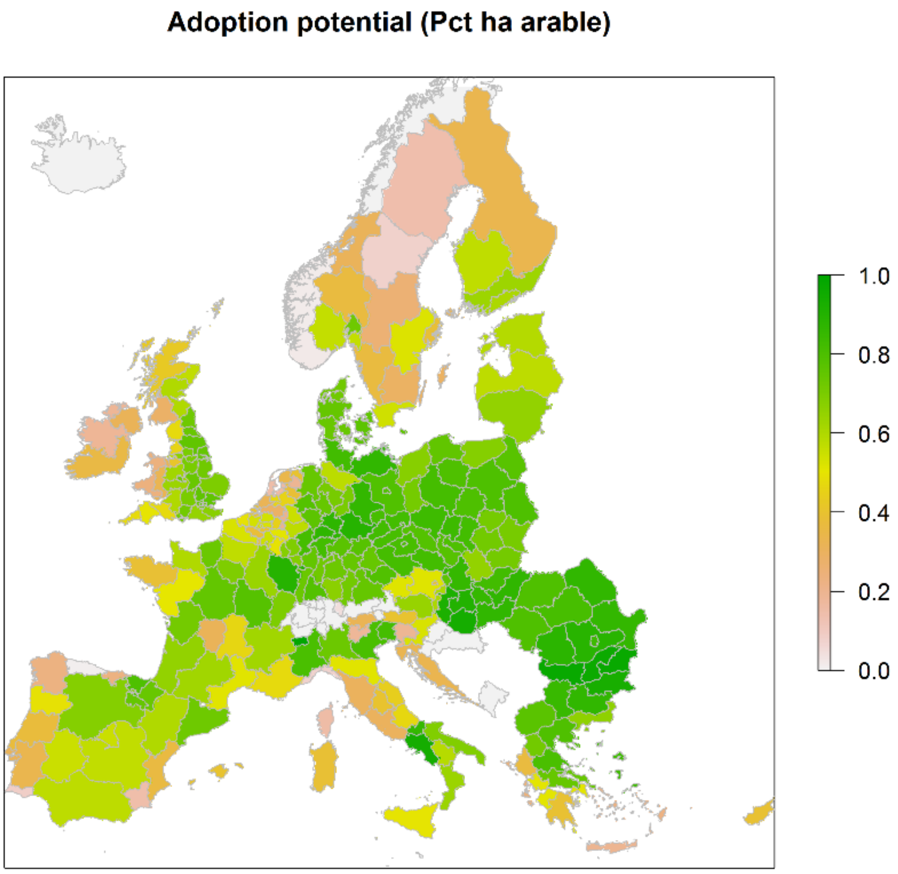


Figure 3.16 Cover crops on arable land in Germany 2015/2016. Source: Statistiches Bundesamt, Fachserie 3. Reihe 2.1.1, 2016. Processed by Wageningen Economic Research.

3.2.2.3 Estimated adoption potentials

From the data on adoption in 2010, it was concluded that in that year in most MSs only a small part of the arable land was covered with a CCC, so that the adoption rate was low, whereas much room for a CCC was available, taking the acreages of bare soils and land with crop residues into consideration (table 3.2). To estimate adoption potential in the different MSs, the assumption was made that at least under or after cereals, industrial crops and green maize (as a major part of the green harvested plant group) a CCC could be grown. Adoption potential was calculated as a share of the total arable acreage per NUTS2-region and presented in map 3.6. [18] Many regions in Central and Eastern Europe show relatively high adoption potentials.

[18] For the calculation of the adoption potential, the assumption was made that CCCs are sown under or after cereals. Therefore, the adoption potential for cereals is calculated as the total area of cereals minus the adoption as reported in the SAPM-study. The assumption for both industrial crops and green harvested plants was that still no CCCs were applied, so that the adoption potential for these two crop groups equals the acreage of these groups. The SAPM-study refers to 20210 data; the current adoption in a number of MSs may be much higher due to e.g. Greening Measures.

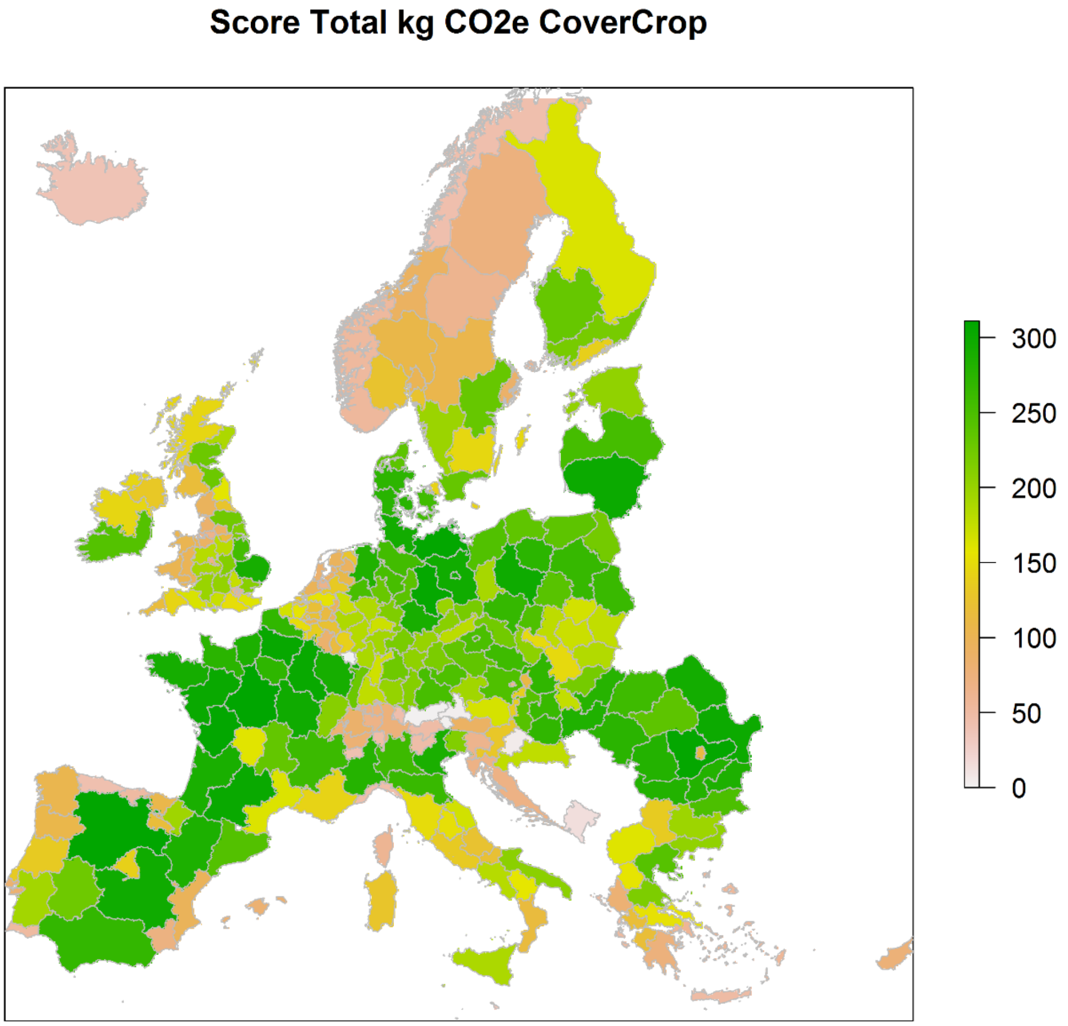


Map 3.6 Adoption potential of growing a CCC (% of total arable land per NUTS2-region)

3.2.3 Combined mitigation and adoption potentials

The combination or product of the mitigation potential per ha (in kg CO2 per ha per year, map 3.5) and the adoption potential (in ha, map 3.6 but in absolute acreages) per NUTS2–region gives the total mitigation potential (in kton CO2 per year) per region. The results are presented in map 3.7. The greener a regio is coloured, the higher the mitigation potential. Such regions are favourites for selection as a case study region. These regions are observed all over the EU, a number of regions in Mid and Eastern Europe, for which a high adoption potential was calculated, but also regions in Germany, Denmark, France, Spain and Italy, partly having high mitigation potentials per ha. A variation on map 3.7 is also separately available for cereals, industrial crops and green maize in Appendix 3 (maps A3.1-3). [19]

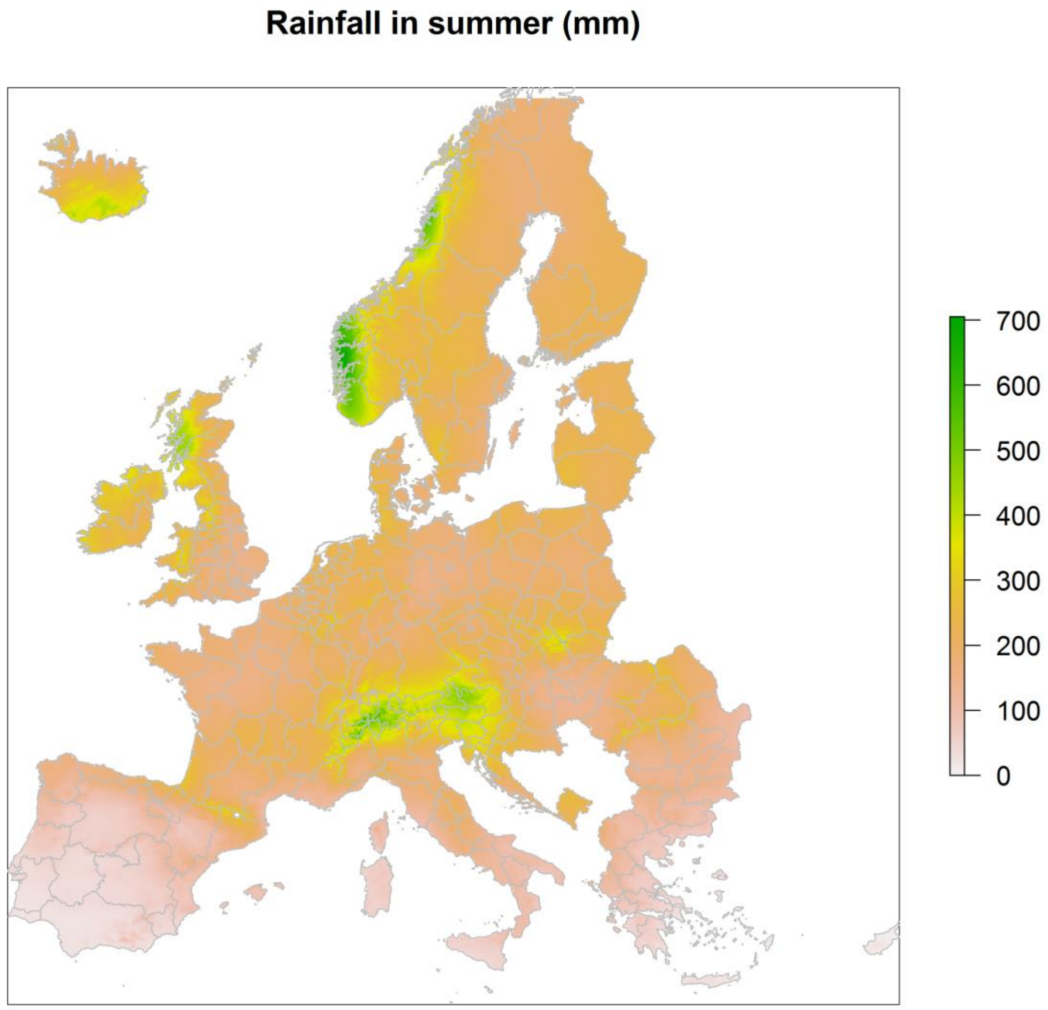
[19] The rankings in the maps in the Appendix are the sum of scores on mitigation per ha and adoption potential, not on the product of these two. The result is more or less the same, since a high score on both leads to a high score on the combination.



Map 3.7 Ranking of total climate change mitigation potential per NUTS2-region. Source: Own estimations as explained in the text.

3.3.3 Availability of moisture after harvest of the main crop

In general, CCCs can be undersown under cereals and green maize. In those cases, the CCC-seed can be sown when sufficient moisture is available in the soil. In the case of industrial crops, like rapeseed or sunflower, undersowing is not common nor easy to perform. In that case, there has to be sufficient moisture in the soil. Harvest is usually in the dry season, which means that there has to be sufficient rainfall for a succesfull CCC, i.e. a good germination process and a rapid growth and production of biomass. Map 3.8 presents the regions with industrial crops and the amount of rain during summer. In South European and North-Scandinavian regions, the opportunities to grow a CCC after an industrial crop are small. In most other regions, rainfall should not be limiting.



Map 3.8 Rainfall during the summer (June – August). Source: Fick and Hijmans (2017), processed by Wageningen Economic Research.

3.3.4 Concluding remarks

Map 3.7 gives a good impression where in the EU both the mitigation potential should be high. In the case of industrial crops, where undersowing is not an option, map 3.8 should be taken into account, showing that it could be too dry for a succesfull estabishment and production of a CCC sown after harvest. In regions with large areas of cereals, industrial crops and/or green maize (map 3.4), there is in general enough time between two main crops to grow a CCC.

3.3 Nitrogen aspects of climate change mitigation

In step 3, the focus is on the nitrogen aspects of climate change mitigation as shown in overview 3.3. Since C-sequestration is the dominant effect of growing a CCC, this step only helps to finetune the main picture, which has already been given in 3.2.

> Overview 3.3 Step 3 - After step 2, assess:
>
> a. where in the EU relatively high amounts of nitrogen are applied, potentially resulting in high risks of N-leaching;
> b. where in the EU relatively high precipitation surplusses are observed, also potentially resulting in high risks of N-leaching;
> c. where the effect of growing a CCC is relatively big for its N-aspect, combining high N-rates and precipitation results.
>
> Step 3 results in additional information compared to step 2, presenting the crops regions with a high potential loss of nitrogen due to leaching as a consequence of a precipitation surplus. Since the N-effect is relatively small compared to the C-effect of a CCC (table 1.2), this step is only helpful for finetuning the selection of case studies.

3.3.1 Risks due to high nitrogen rates

Part of the risks of nitrogen losses during and after crop cultivation have been described 1.4.2. A conclusion was, that the climate change mitigation effect of CCCs through reduced N-fertilisation and N-emissions is relatively small compared to the effect of C-sequestration, although the contribution of nitrogen to the greenhouse effect is rather big. [20] Throughout the EU, there are differences in risks of N-losses due to climatic differences. Therefore, estimations of the mitigation effects should ideally be carried out within agri-environmental zones (AEZ, including climatic zones), as described in 2.4.

Lack of data on AEZ throughout the EU led to the short-cut to take average N fertilisation rates as an indicator for potential N losses and, as a consequence for potential mitigation effects as far as the nitrogen balance is considered. Map 3.9 gives an overview of these levels in arable and grassland in the EU. High nitrogen rates are monitored in a wide Atlantic coastal zone from Denmark to Mid-France, in Switzerland and Austria and in some regions of Italy (Po-valley) and Spain. In regions with rather intensive farming systems and high yields, such as cropping plans with root crops in North western Europe, the N-input per ha is high. In South and Eastern Europe, cropping plans are less intensive, have a larger share of cereals and industrial crops and a lower N-input per hectare.

High nitrogen supplies affect nitrogen surplus in the soil after the main crop is harvested. The combination of map 3.9 with maps of the 'big crops' (in 3.1) and with climatic data for the summer (map 3.8) or the winter period (map 3.10) gives an indication of the climate change mitigation potential for the N-aspect. In general, the conclusion is that regions with a high (root) cropping intensity, like in the Atlantic coastal zone, in the PO-valley and in some Central-European countries have relatively high N-input rates. In these regions, the risks of high N-losses and the opportunity to save N-fertilisation are relatively high, leading to relatively high mitigation effects from the nitrogen point of view. [21] In the selection of the case study-regions, this should be an aspect to take into account.

The real level of mitigation depends, besides the adoption rate and the soil type, on the effectiveness of the crop cover (mixture) selected and other management practices, which is described in 3.6.

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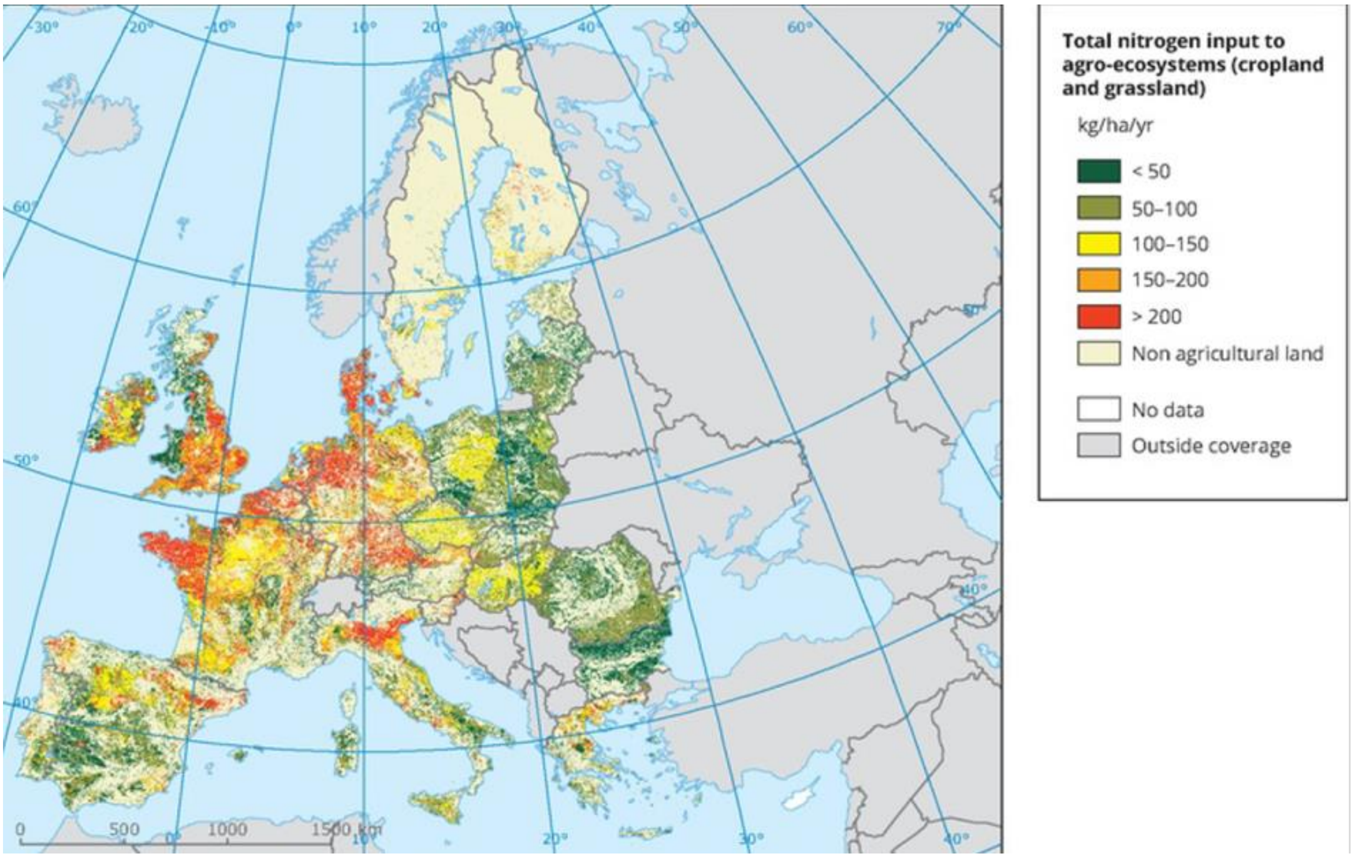
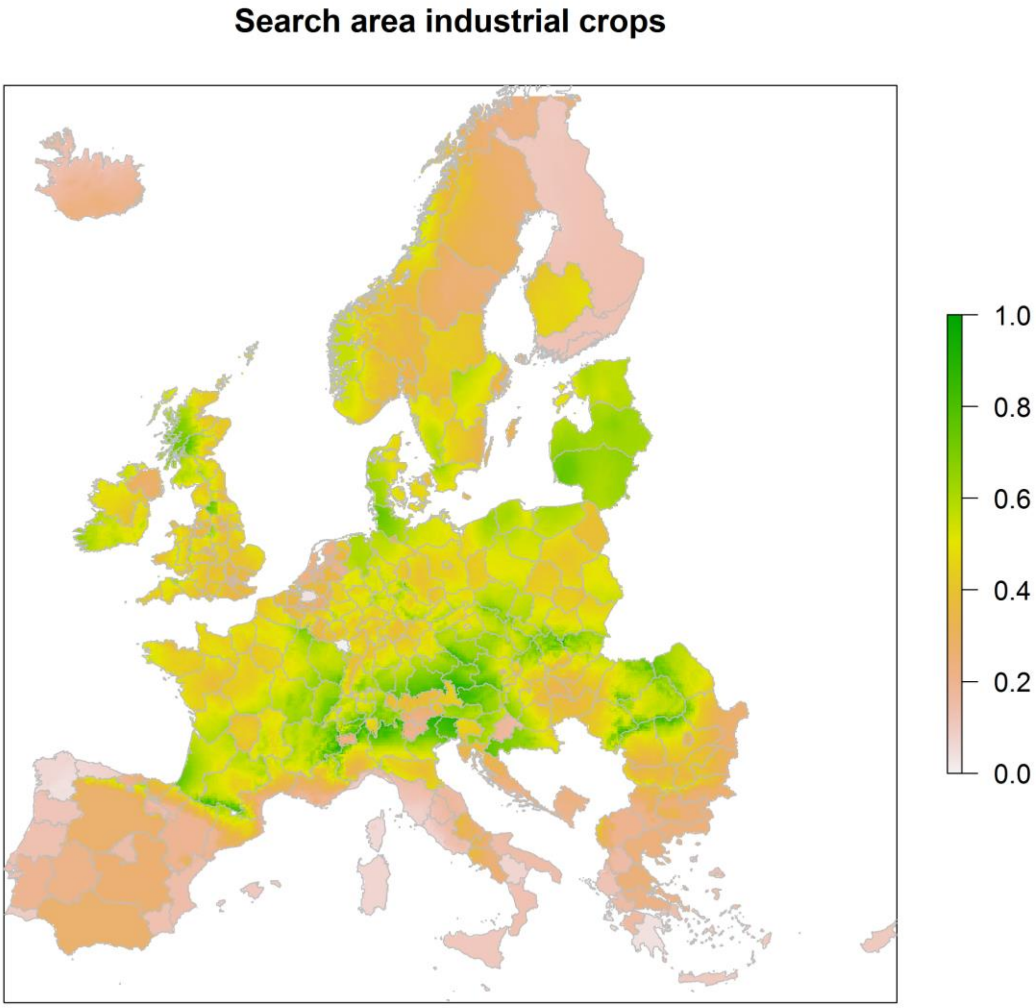
[20] Other GHG have different effects on the climate but could be expressed in terms of CO2-equivalents: 1 kg of nitrous oxide (N2O) = 296 CO2 equivalents; 1 kg of methane (CH4) = 23 CO2 equivalents.
[21] The climatic zoning of Köppen-Trewartha gives an overall picture of weather conditions in the EU (Appendix 4).



Map 3.9 Total nitrogen input to agro-ecosystems (cropland and grassland). Source: https://www.eea.europa.eu/downloads/744070669ce04eea8b02ad246e644f39/1447668707/total-nitrogen-input-to-agro.pdf

3.3.2 Risks due to much rainfall

Map 3.10 gives for the different regions in the EU scores for the conditions for crop growth (e.g. for industrial crops), focusing on the amount of rainfall. The higher the score, the higher the yields of crops due to higher rainfall figures. This map can also be used to assess where high leaching risks could occur, especially in combination with high N-rates, as discussed in 3.3.1. The most favourable conditions for leaching due to high N-rates and high precipitation figures are found in the Po-area, Austria and Denmark.



Map 3.10 Score of potential crop production per region resulting from rainfall specifically.[22] Source: Public data, adapted by Wageningen Economic Research.

3.4 Cost-benefit analysis of growing a CCC

Overview 3.4 gives information on step 4. Table 3.3 shows results of CCC-application in the Netherlands. In this application, there is a positive net financial effect, taking the value of the organic matter into account (tabel 3.3). The costs for the seeds and for sowing are additional to leaving the soil bare. On average they amount 200 euro/ha. In some cases, a herbicide application is required to destruct the CCC before the next crop, which results in additional costs. For the Netherlands, the cultivation costs of growing a CCC amount 400 euro/ha at maximum.

Growing a successful CCC always leads to a higher yield of the next crop compared with a farming system without a CCC. The total added value of a CCC (table 3.3) depends on the extra yield of the next main crop, which in turn depends on the variable effects of a CCC on water management, nutrient leaching, soil structure and soil health (Zwart et al., 2017).

[22] This map is almost similar for cereals and green plants.

Overview 3.4 Step 4 - After step 3, assess whether the cultivation of CCC is feasible in these regions from the point of view of an attractive cost-benefit-balance:

a. Costs refer to:
   i. Seeds;
   ii. Fuel for tillage and sowing;
   iii. Labour for tillage and sowing;
   iv. Possibly: herbicide to destroy the CCC before sowing/planting the following crop;
b. Benefits:
   i. Climate change mitigation;
   ii. Saving on N-rate in the following crop;
   iii. Yield increase of the following crop;
   iv. Increase of organic matter content of the soil. c)

Step 4 results in additional information compared to step 3, presenting the regions where the cost-benefit balance of growing a CCC is positive and adoption by farmers more likely.

Table 3.3 Costs and benefits of different CCC-species applied in the Netherlands

CCC-species	Costs (euro/ha) a)	Value organic matter (euro/ha) b)	Value of N (euro/ha) c)	Total added value (euro/ha)
Cruciferous	180	255	45	120
Rye grass	220	330	45	155
Red Clover	200	330	65	195
White Clover	200	255	65	120

a) Seed costs + 100 euro sowing costs per ha;
b) Value of 0.30 euro per kg effective organic matter; [23]
c) Assuming a fertiliser price of 1.11 euro/kg N.

Source: WUR-PAGV, Handbook Soil and Fertilisation; KWIN 2015

The cost-benefit evaluation in this section assumes a long-term vision of farmers. In practive, the level of cash flow can be an important factor in decision making. Cultivation costs of 200 – 400 euro/ha of CCC can be perceived as high when crop margins are relatively low. In 159 out of 277 NUTS2-regions with data on cereals productivity, the average returns were smaller than 900 euro/ha, assuming a cereal price of 150 euro/ton. In those cases, costs of 400 euro for the cultivation of a CCC would imply that the variable costs of the cereal crop itself could not be more than 500 euro/ha to have some margin left at all. These regions are mainly found in Eastern and Southern Europe.

Concluding, from a long-term view it is always beneficial for farmers to grow a CCC. In regions with low productivity, the cash flow could be too low to make adoption feasible for the farmers. That problem could partly be solved through additional benefits from policy side, the theme of the next section.

3.5 Contribution of policies to adoption of CCCs

[23] This value is calculated from changes in the organic matter balance in the soil i.e. the net increase of effective organic matter and its added value in terms of a yield increase and, as a consequence of an increase in returns of the next main crop. According to De Haan (2015), this value can be much higher. He calculated an average price of 0.80 euro/kg, measuring a net contribution of 800 – 1,200 kg effective organic matter per ha CCC.

Overview 3.5 Step 5 - After step 4, assess the overlap with legal obligations to grow CCC, e.g. to comply with the Greening Regulations and other policies

After step 3, the overlap with legal obligations and other policies to grow CCC was assessed, specifically to comply with the Greening Regulations or the Nitrate Directive.

In an evaluation of the 2013 Greening measures (Alliance Environnement and the Thünen Institute, 2017,), the following conclusions were drawn:

- Farmers declared a much higher proportion of their eligible arable area as EFA than required (9.7% compared to the required 5%), although percentages differ at farm level.
- The total areage (before applying weighting factors) declared as EFA in 2016 was 8.5 million ha, or 14% of EU arable land.
- The main types of EFA declared by farmers at EU level are linked to productive or potentially productive areas: N-fixing crops and catch crops (together 73% of the total EFA area in 2016), followed by land lying fallow (24%). Landscape features come fourth with 1.4% of the total EFA area in 2016 (Alliance Environnement and the Thünen Institute, 2017,).

The question is if the EFA-obligation stimulated the growing of catch and cover crops. [24] The acreage of intermediate crops in table 3.2 (derived from the SAPM-study) was 5.9 million ha. The acreage of CCCs in 2016 was 73% of 8.5 million ha or 6.2 million ha, an increase with only 0.3 million ha or 5%. The effect of the Greening Regulation was therefore relatively small: this increase of acreage is compared to the total area of cereals, industrial crops and green plants (77.3 million ha in 2013) only an increase of 0.4%. This conclusion is in agreement with the findings by Van der Meulen et al. (2017), that farmers in the Netherlands mainly declared existing acreages of CCCs as EFA. In some MSs, there was the option of fallow land. This option may have hindered a maximum adoption of CCC.

In terms of effects, the evalation study concludes that the EFA measure is one of a range of factors driving an increase in the area cultivated with N-fixing crops, such as pulses, soybean and green fodder (besides VCS, the crop diversification measure and market developments). It has also helped spread the use of catch and cover crops in some regions (FR, DE, CZ, UK-En), although this is also influenced by requirements under the Nitrate Action Plan (e.g. in NL) or under cross-compliance (Alliance Environnement and the Thünen Institute, 2017).

The Nitrates Directive of the EU (http://ec.europa.eu/environment/water/water-nitrates/index_en.html) aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. The Nitrates Directive forms an integral part of the Water Framework Directive and is one of the key instruments in the protection of waters against agricultural pressures. One of the ways of implementation is the establishment of Codes of Good Agricultural Practice to be implemented by farmers on a voluntary basis. Codes should include e.g. crop rotations, soil winter cover, and catch crops to prevent nitrate leaching and run-off during wet seasons. In the Netherlands, the Nitrate Directive has led to the obligation to grow CCCs under or after green maize (www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid/mest/vanggewas-na-mais).

[24] If a farmer does not want to comply with Greening, he can decide not to apply for direct payments from Pillar 1 in the GAP. In that case, he is not obliged to comply with the Greenings Regulation.

3.6 Management practices

This section contains an overview of management practices of CCC including species and mixtures of species as applied in agricultural practice and costs and benefits.

3.6.1 Available species for CCC

Appendix 2 gives an overview of the species that can be used as a cover crop (in different languages, appendix 2A), their characteristics and a qualitative estimation of their climate change mitigation effect (appendix 2B) and an overview of sowing periods (appendix 2C). The list is composed of different cover crop types:

- Cereals and grasses:
  - Annual cereals;
  - Annual or perennial cereals;
  - Annual or perennial grasses;
  - Warm-season grasses;
- Brassicas and mustards;
- Legumes;
- Others, like line and buckwheat.

3.6.2 Management practices of CCC

3.6.2.1 Cover crop management in general

The general scheme to manage a cover crop is as follows (https://www.gov.uk/countryside-stewardship-grants/winter-cover-crops-sw6):

- Remove any areas of soil compaction but do not subsoil on archaeological features;
- Establish the cover crop by 15 September [25], so it can take up soil nitrate before winter drainage water leaches it below the depth of the developing plan;
- Establish the crop by drilling or broadcasting;
- Sow at a suitable seed rate to provide a dense cover and protect from soil erosion;
- Destroy the cover crop in late January or February, before it is too well developed – if left too late nitrate leaching may increase the following winter;
- Cover crop destruction may include an application of glyphosate prior to destruction by cultivation for the following crop.

Planting and destruction (also called cover crop termination) are the two main phases in cover crop management. When looking closer to this, one can distinguish detailed properties of management practices such as land preparations, sowing density, sowing depth, weeding, pest and disease control, fertilisation and irrigation. Justes et al. (2017) conducted a literature review and analysis on the two main management phases (planting and destruction), their dates and implementation conditions, with the aim to identify the different methods and, if possible, their effectiveness with respect to the success. A brief summary is given below (more information in Justes et al. (2017) pp. 13-17). Information about cover crop planting and establishment methods can be found in chapter 4.1.3 of White et al. 2016.

After the desired growing period the cover crop has to be destructed, whereby the timing depends on the desired functions of the cover crop and the requirements of the next crop. Balkcom et al. (2012) speak of a general rule one can hold on to: cover crops should be destroyed two to three weeks before seeding or planting the following crop. The timing of killing the cover crop has an effect on soil temperature, soil moisture, nutrient cycling, tillage and drilling operations of the following crop and potential impact of allelopathic compounds on the following crop establishment (Clark 2012; Balkcom et al. 2012; Bronick and Lal, 2005). Cover crop destruction can be carried out mechanically (e.g. ploughing) and chemical

[25] This may be a different date in other, e.g. Southern member states compared to the UK.

(e.g. glyphosate) methods or natural mechanisms (e.g. frost). When choosing chemical destruction methods, e.g. a non-selective herbicide also destroying potential weeds, one has to take into consideration that the continuous usage of this, might lead to the development of herbicide resistance (White et al. 2016). It can however easily be combined with a reduced tillage system. Cover crop termination without the use of synthetic herbicides relies on mechanical practices or frost. Mechanical destruction of cover crops can consist of mowing, roller crimping, undercutting and tillage (ploughing) (see picture 3.1). In the first and second mechanical termination method, cover crop regrowth due to incomplete termination might compete with the following cash crops for water and nutrients (Vincent-Caboud et al. 2017). Several authors discuss the importance of termination timing; according to them a cover crop must reach the flowering growth stage, to be successfully controlled (Moyer, 2011; Mischler, 2010). Cover crop termination was discussed as one of the main challenges of Northern European organic farmers for adopting conservation agriculture and specifically no-tillage (Casagrande et al. 2015).

Picture 3.1. Cover crop termination techniques (fltr): mowing, roller crimping, ploughing

A major conclusion drawn by Justes et al. (2017) is how little scientific literature is available on fallow period management practices. This is confirmed in a research review performed by White et al. (2016). Furthermore, it is confirmed in the most recent review of farmers' practices on organic cover crop management techniques in Europe, written by Vincent-Caboud et al. (2017). The authors of the latter paper call for research on four key agronomical issues: choice of cover crop species, increasing cover crop biomass, cover crop termination and crop rotation. In the book by Justes et al. (2017), the authors refer to more practical publications of e.g. technical institutes and chambers of agriculture. Many of the below listed information is drawn from these sources, as advised by Justes et al. (2017).

3.6.2.2 Cover crop management for crop categories

A frequently used categorisation of cover crop species is used to specify and further describe the cover crop management practices in more detail (adopted from: Magdoff et al. 2015; White et al. 2016). The categorisation is being based on crop families, all families having contrasting properties e.g. a characteristic root system, growth cycle and distinctive abilities to deliver a diverse range of services to the functioning of the overall farming system. A distinction has been made between grasses (e.g. rye, wheat, oats, sorghum sudan), brassica's (e.g. tillage radish, mustard) and leguminous (e.g. red clover, alfalfa, vetch, field peas). Furthermore a fourth category has been added with species not falling in the three above named crop families (e.g. line seed, buckwheat). When choosing a cover crop mixture one has to realise that the complexity of management practices required might be greater than when choosing a monoculture of cover crop species.

Grasses

Grasses used as cover crops such as winter rye, barley and oats can be generally characterised as providing benefits such as their ability to scavenge nutrients, such as N, left from a previous crop. The extensive root systems of grass cover crop species establish rapidly and can reduce the erosion potential of the soil. Besides that, they produce large amounts of crop residues and add organic material to the soil. Grasses are higher in carbon content than for example legumes, so the residue tends to last longer in the soil before breaking down, which can make grass cover crops potentially beneficial for weed control. Due to the high C:N ratio of the grasses residue (which increases when grasses mature), it makes it difficult for the following (cash) crop to access the nitrogen from the grass cover crop residue. However, the slower decomposition and higher C content can potentially lead to an increase in (more stable) organic matter. Standard management practices of an annual cereal grain consist of seeding in late summer or fall, to establish a good root system before becoming dormant in winter. Some advice not to fertilise a grass cover crop in spring (as one of the main role of a grass cover crop is to scavenge for nutrients) (Clark, 2007). Similar to the general management practices of all cover crops, it is advised to kill the crop 2-3 weeks before planting a cash crop. However, in colder climate regions in Europe, with possibly high rainfall in spring, this can be slightly longer due to the necessary yet slow heating and drying of the soil in these regions. Subtle differences exist between management practices for different grass cover crops. We refer to the handbook Managing Cover Crops Profitably, 3rd Edition, (Clark, 2007) for more details.

Brassicas

Brassica cover crops such as radishes, turnips and mustards can be generally characterised as providing benefits such as good ground cover and deep rooting. They have the ability to mitigate leaching risks and improve soil structure. Other benefits are the rapid growth in autumn and our good understanding of brassica agronomy (White et al. 2016). Some Brassica's have a deep tap root and are also called tillage Radish, as they can break down plough pans. It can also be called 'biodrilling'. Besides, most Brassicas are easily killed by winter frost and thus preferred if one needs an early spring seed bed and/or one cannot use ploughing or tillage to break down the cover crop. One great disadvantage of (some) Brassica cover crops is the fact that remains of a crop in the Brassica family might increase risks of prevalence of Clubroot (Plasmodiophora brassicae) in a rotation with cabbages as cash crops. In the Dutch cover crop management guidelines it is e.g. advised not to grow yellow mustard in a crop rotation with cash crop cabbage.

Legumes

Commonly used legume cover crops can be winter annuals such as crimson clover, hairy vetch and peas. However, a legume can also be a biennial such as sweet clover or a perennial, like red clover and white clover. The legume cover crops are famous and well-regarded for the atmospheric nitrogen (N) fixing capabilities, to be used in the subsequent crops. Depending on their specific root system, they can be used to reduce or prevent erosion. In comparison to e.g. cover crop grasses, legumes are very attractive for nectar-eating insects. In comparison to cover crop grasses, legumes have not such good weed competing abilities, especially in the early growing stages of the legume cover crop. According to the Midwest Cover Crops Field Guide: 2nd Edition, legumes need to be sown earlier then brassica's and legumes due to the fact that the seeds of a legume have a need for higher minimum germination soil temperatures compared to e.g. small grain seeds. Another management issue showing around the corner whilst planting: many sources advice to inoculate the seeds to insure proper nodulation – and thus ensuring the N fixing capabilities of the legumes. However, this is not standard practice in e.g. the Netherlands. Yet, the benefits of leguminous cover crops on the following crop and the N availability after the cover crop are clear.

Olives

Cultivating live cover crops is currently one of the dominant directions in sustainable olive production (Gomez-Calero et al., 2009). The selected species for use as cover crops in olive orchards are mainly grasses and legumes, often sown in mixes of several species. Grasses are resistant against the passage of machinery and their intense rooting makes them excellent in erosion prevention. Legumes are attractive mainly for their ability to provide nitrogen which allows for a reduction in fertiliser application. The main concern when choosing cover crops as a management tool and selecting cover crop species is the risk of water competition during the dry season when the most important biological processes of olive production take place. One way to avoid competition of water but still maintain erosion protection is by only sowing cover crops on one side of the trees. Some authors believe that a minimum annual rainfall of 500 mm is required for cover crop cultivation (Pardini et al., 2002).

Natural cover cropping of native species is the most common and economically beneficial cover crop practice in use. These cover crops are very strong competitors, especially for water which poses a risk to the olive production. On the positive side, they are persistent and require little management. *Sown* cover crops that are not naturally occurring are less persistent and are more likely to require re-sowing after a few years (Labrador et al., 2011). Because of a complementary life cycle, some research suggest that annual legume species such as subterranean clovers are suitable for areas with an annual rainfall of less than 700 mm (Longhi et al. 2002). Because of the autumn-spring cycle of the annual legumes the competition for water in the dry season is minimal. Currently, the use of these self-seeding annual legumes is wide-spread, partly to the large variation is species choice, providing several option for each condition. Above 700 mm is it possible to use perennial legumes, however perennial grasses are preferred (Pardini, 2001). The perennials may compete more with the tree growth and hence require irrigation (Pardini et al. 2002).

Generally, cover crops are sown in the autumn in large seed quantities, a few years after the planting of the olive trees to allow for tree establishment. The cover crops are managed by periodically cutting to 4-5 cm height during spring and summer and leaving the residue on the ground as a mulch. The number of cuts varies between 1-4 dependent on the risk of spread of weed seeds and the degree of competition with the olive trees (Pardini et al., 2002).

Cover crop management for specific EU climate zones

The Mediterranean type of climate is characterised by a limited, and highly variable, precipitation level in relation to the potential evapotranspiration (ETo) and by a dry season during the period of maximum temperature and ETo (Gomez, 2017). This specific climate has led to some main, agricultural management practices, in the direction of prioritising (the sometimes scarce) soil water availability in the orchards (wine, olive: one of the larger agricultural land uses in the Mediterranean). Three major elements in this agricultural management are: 1) a low tree plant density, 2) a pruned canopy size, and 3) elimination of weeds to reduce the competition for the limited source of soil water. This has led to an agricultural landscape with bare soil due to no soil cover by either weeds or a cover crop. However, it is also under such conditions very beneficial to cultivate a cover crop, as issues caused by this specific management are: water erosion, decreasing water quality due to offsite contamination, decrease in biodiversity and an increasing pressure on water resources (Beauffoy, 2001).

In order to avoid competition for water with the trees, cover crops in Mediterranean orchards are always temporary and coincide with the rainy reason (fall and winter). The practice consists of seeding or letting naturally present flora grow and thereafter destructing the crop in early spring chemically or mechanically. The residues are left on the ground and ideally the cover crop will regrow next autumn from the seeds produced previous year. In olives and vines, there is a trend towards using short grass species with an adapted phenology where the growing cycle is several weeks shorter followed by early seed development. Mixtures of flowering species to achieve an increase in biodiversity has also been tried resulting is a large decrease in diversity already after a few years (Gomez et al. 2014). Still, the practice of seeding a cover crop is very rare and the most common practice is letting the present flora grow (Gomez, 2017). In general, cover crops are difficult to establish under the warm and dry conditions of the Mediterranean which is why few farmers have experience with use of cover crops (Vincent-Caboud et al. 2017).

In Northwestern Europe the use of cover crops is more widely spread than in the Mediterranean region. However, cover crops are rarely combined with non-tillage systems, while this practice is more common in the Mediterranean in order to combat erosion. Most north western European farmers terminate the cover crops by undercutting or mowing and only 2% by crimping. The humid conditions of north western Europe enable cover crops to be established quickly and large volumes of biomass to be produced, hereby also making the termination of the cover crop a challenge. The difficulty of termination is especially large with legumes. Additionally the high moisture conditions cause an increase in weed development and rapid degradation of cover crop residues, which can be problematic when aiming to synchronise the degradation of the cover crop with nutrient uptake of the subsequent crop. Another issue with cover crops in the north is the slow warming of the soil when cover crops are present (Vincent-Caboud et al. 2017).

3.6.3 Example and description from France

An important source for the information in this section is Justes (2017).

Cover crops are usually sown after the previous main crop has been harvested, although they may also be undersown with the main crop. [26] After harvest, these CCCs are generally sown between late July and early September and destroyed between November and February of the following year. Their growth period therefore ranges from 2 to 6 months, depending on crop rotations and regions. They may be destroyed naturally by frost, mechanically (chopping, ploughing, surface stubble ploughing) or chemically, by the application of a systemic foliar herbicide (glyphosate, for example), depending on the type of crop and the maturity of the plant cover, but also the regulations in force, which, in numerous cases, prohibit chemical destruction processes.

Current fallow period management practices in France were studied on the basis of information obtained from the 'Pratiques culturales en grandes cultures' ('Arable cropping practices') survey conducted in 2006 by the French Ministry of Agriculture's Department of Statistics and Forward Studies. Since the results of the last survey conducted in 2011 were not yet available, this review of practices does not take into account the impact of the 2008 nitrates directive relative to autumn soil cover in "Nitrate vulnerable zones" (NVZs).

In the sample covered by the 2006 survey, 7.8 % of the fields surveyed were planted with a catch crop and 20% had previously crop volunteers. The majority of cover crops are Brassicaceae (66 %), with a large proportion of white mustard, which has "nematode control" properties, and 25 % are Poaceae; the use of mixed crops or other botanical families is not common (4–5 %). Soil cover practices during fallow periods are revealed to be highly diversified, in terms of extent (0–20 % of the area), the cropping practice methods used to plant and destroy these cover crops (volunteers destruction, the survey indicates that mechanical chopping and/or burying (ploughing) are the main methods used in France.

The decision to use a cover crop depends on the crop that succeeds it: hence in 2006, for example, 48 % of sugar beet crops, 37% of potato crops, 21% of spring pea crops and 14% of maize crops were preceded by a cover crop, representing a very marked increase from 2001, when the respective percentages were 21, 18, 4 and 5% (Agreste Primeur, 2004). However, the planting of a cover crop still only happens in 4.5 % of the fields before sunflowers (1% in 2001) and in less than 4% of fields before spring barley. [27]

The great majority of cover crops follow straw cereal crops (13 % of wheat crops, 10 % of barley crops and 11 % of other cereal crops are followed by a cover crop) and, to a lesser extent, silage maize crops (6 % of maize crops). The practice of allowing previous crop volunteers to grow after harvest remained stable overall between 2001 (18 % of annual crops) and 2006 (20 %), although a few changes occurred. The previous crops concerned are primarily oilseed rape (volunteers are present in almost half of the fields in which oilseed rape crops have been grown), then straw cereals (29 % of fields with a previous durum wheat crop, 27 % of those with a previous common wheat or barley crop and 21 % of those with a previous other cereal) and protein crops (26 % of fields with a previous protein crop).

Statistical analysis of the sample surveyed in 2006 led to the definition of eight main types of cover crop management. These eight management types correspond to cropping practice combinations that differ depending on the region and the main type of production system (arable, mixed arable/livestock farming or livestock farming).

Overall, the major results are as follows:

• Type 4, which accounts for 17% of fields in the sample, is characteristic of cover crop management in an arable context in the Northern half of France: planting of mustard following wheat or barley, between 15 August and 15 September, destroyed mechanically between 1 November and 15 December, without organic manuring, before sowing a sugar beet, pea, grain maize or spring barley crop.

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[26] A rough estimate is that about 25% of the CCCs is sown under the main crop.
[27] It is not known why farmers do this differently for different following crops.

• Types 1–3, which are characteristic of both arable and mixed arable/livestock contexts, differ from type 4 as organic products (manure, compost) are applied before the cover crop is sown (type 2) or at the time of sowing (types 1 and 3). They differ in terms of the cover crop sowing period (earlier for type 3), the type of crop sown or the kind of organic matter applied, and in terms of the cover crop destruction period (later and variable for type 1).

• For types 5–8, organic fertiliser (manure) is often applied, at the time of destruction or shortly after destruction of the cover crop. These inputs therefore do not concern the cover crop but, rather, the next crop. The proportion of fields concerned by this practice is different in each type.

3.7 Synthesis

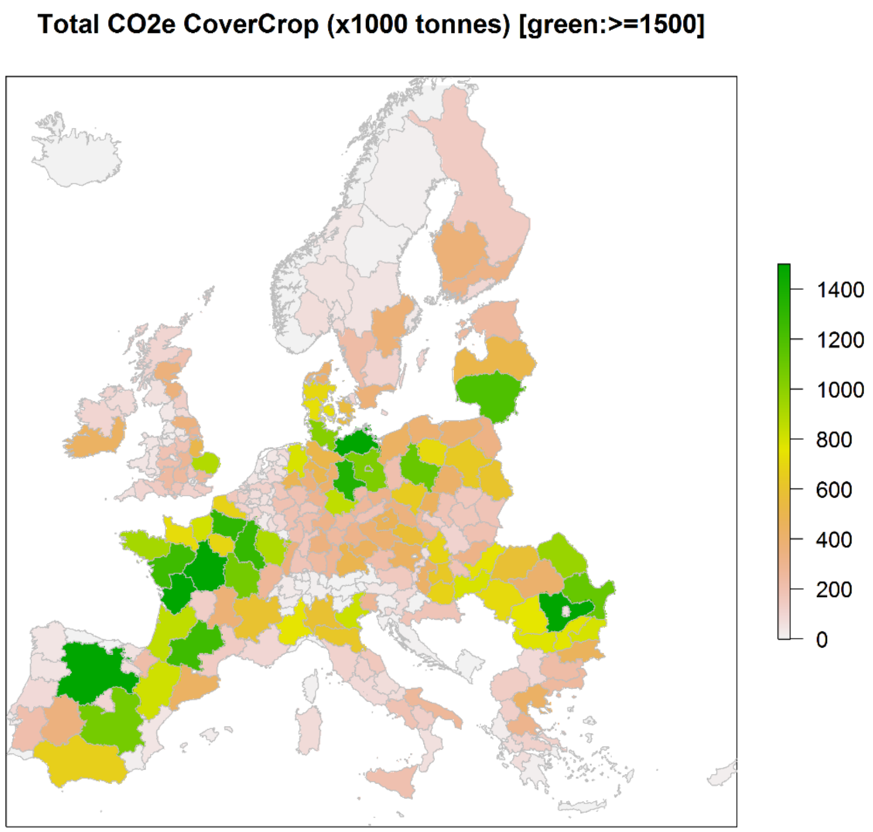
The selection of case studies will be based on a shortlist, which will be narrowed down in phase 2 of the project. The shortlist from the data collection and analysis in this report is presented in table 3.4 and illustrated in map 3.11. Andalucia in Spain scores high, because of a high estimated climate change mitigation of olives in that region: 2.3 million ton kg CO2e, which directly follows the first region that was ranked for the three big crop groups (cereals, industrial crops and green maize), the region Centre in France, with an estimated mitigation potential of 3.7 million ton kg CO2e per year.

Table 3.4 Shortlist of case studies to select from for the design of the survey

Number a)	Region	NUTS2 number	Farming system/crop	Priority level b)	Remarks
1	Centre, France	FR24	Mainly cereals	High	
2	Andalucia, Spain	ES61	Olive	High	Option of mulching, dry summers, also high score in ranking of 3 big crop groups
3	Castilla y León, Spain	ES41	Mainly cereals	High	
4	Mecklenburg-Vorpommern, Germany	DE80	Green maize – cereals – industrial crops	High	
5	Poitou-Charentes, France	FR53	Cereals – industrial crops	High	
6	Sud – Muntenia, Romania	RO31	Cereals – industrial crops	High	Not many adopters?
7	Sachsen-Anhalt, Germany	DEE0	Green maize – cereals – industrial crops	High	
8	Picardie, France	FR22	Cereals – industrial crops	High	
9	Champagne-Ardenne, France	FR21	Cereals – industrial crops	High	
10	Midi-Pyrénées	FR62	Cereals – industrial crops	High	
11	Pays de la Loire, France	FR51	Green maize – cereals – industrial crops	High	
12	Lithuania	LT00	Cereals	High	
13	Niederösterreich, Austria	AT12	Cereals	Medium	High adoption rate
14	Overijssel, the Netherlands	NL21	Sugar beet – potato – onion - cereals	Medium	High adoption rate

a) Priority level for selection as concluded in this task;
b) Priority level according to table 1.1.

Source: Ranking according own methodology as described in chapter 2.



Map 3.11 Total mitigation potentials (in kton CO2 per year) per NUTS-region. This map does not include permanent crops. Source: Own estimations as explained in the text. Maps for the three separate big crop types are given in Appendix A3.4-6.

In table 3.4, French, Spanish, Romanian, German and Lithuanian regions dominate the ranking order. Many of these regions have rotations with mainly cereals and industrial crops. The two German regions include also green maize, which is interesting from the point of view of the nitrate leaching aspect (1.4.2). The French region Champagne also has considerable acreages of vineyards, a permanent crop with opportunities and a necessity to grow CCCs, since they are often located at slopes.

The order of case studies in table 3.4 is in the first place dominated by the fact that big crops have large acreages and a high mitigation potential in terms of the total potential effect when CCCs are successfully grown: total area * mitigation potential per ha * (increase in) adoption rate. A second criterion for the selection in the shortlist was to include a diversity of farming systems: crop rotations with cereals and industrial crops, crop rotations with green maize (probably including mixed farms) and farming systems with permanent crops. In different farming systems, farmers may make different choices, e.g. depending on costs of using CCCs, expected effects on the profitability of the farming system as a whole, etc. Different climate zones were included to investigate if that factor makes a difference for adoption and if nevertheless successful ways of growing a CCC can be identified. A third criterion was to include geographical diversity, which is represented in the shortlist with MSs from Southern and Northern, and Eastern and Western Europe. These MSs also represent different political/regulatory environments, a fourth criterion. In Northwestern MSs relatively high N-fertilisation rates are applied in combination with relatively high precipitation levels. In these regions, the authorities are more focused on adoption of leaching avoiding measures (e.g. growing CCCs) than in Eastern European MSs with drier conditions.

The shortlist had to contain also some cases with medium priority. Those could be:

- Vineyards in Bourgogne, France. Adoption rate seems to be low there. It could be that wine-farmers are afraid of diseases like fungi from plants growing between the rows, so the space between the rows is often left bare;
- Austria, with high adoption rates (risk of erosion could be a factor, though);
- A crop rotation with potato, sugar beet, cereals and/or onion and/or carrot, as found in North-West European MSs, like Belgium, the Netherlands, Denmark and parts of Germany, UK and Northern France. The adoption rates and mitigation potentials are relatively high in these regions, especially in the Netherlands.

An option for the case studies is to cluster neighbouring NUTS regions in a member state into one combined case study region. This could e.g. be useful for number 14, the province of Overijssel, which is a relatively small region with a relatively small area of arable land. It could be combined with e.g. the province of Flevoland, a province with much more arable land but with lower shares of cereals in the cropping plan.

More details on the estimated adoption and climate mitigation potentials of the regions in the shortlist are given in table 3.5. From the shortlist and this table, a preliminary list of case study regions was made:

a) France: Centre, Poitou-Charentes, Picardie, Champagne-Ardenne, Midi-Pyrénées or Pays de la Loire;
b) Spain: Andalucia, perhaps also Castilla y León;
c) Germany: Mecklenburg-Vorpommern or Sachsen-Anhalt;
d) Sud – Muntenia, Romania or (total) Lithuania;
e) Niederösterreich, Austria or Overijssel, the Netherlands.

Table 3.5 Adoption potential and mitigation potential of CCCs (per ha and in total) for the NUTS2-regions in the shortlist (table 3.4).

NUTS2-region		Total adoption potential (1,000 ha)	Mitigation potential (kg CO2/ha/ year	Total mitigation potential kton CO2/year	Ranking			Overall Priority b)
Number	Name				Adoption potential a)	Mitigation potential/ha	Total mitigation potential	
FR24	Centre (FR)	1,541	1,544	2,379	309	243	311	1
ES61	Andalucía	1,550	1,470	2,278	Estimation of olive potentials from literature			2
ES41	Castilla y León	2,295	942	2,162	311	113	310	3
DE80	Mecklenburg-Vorpommern	934	1,726	1,612	299	272	309	4
FR53	Poitou-Charentes	1,028	1,493	1,535	303	228	308	5
RO31	Sud - Muntenia	1,627	938	1,527	310	111	307	6
DEE0	Sachsen-Anhalt	862	1,577	1,359	297	252	306	7
FR22	Picardie	670	1,948	1,305	282	296	305	8
FR21	Champagne-Ardenne	787	1,633	1,284	291	263	304	9
FR62	Midi-Pyrénées	1,005	1,246	1,251	301	182	303	10
FR51	Pays de la Loire	829	1,508	1,250	294	240	302	11
LT00	Lithuania	1,485	809	1,202	307	92	301	12
AT12	Niederösterreich	356	1,241	442	240	179	247	65
NL21	Overijssel	31	1,682	52	94	270	109	203

a) For the medium priority cases (AT12 and NL21), the adoption potential should be relatively low but the adoption rate should also be relatively high. A low adoption potential was also calculated for regions with relatively small acreages of cereals, industrial crops and green maize. From the SAPM-study, additional information for the these two regions was included in this selection.

b) Based on ranking on total mitigation potential per region.

4 Conclusions and discussion

4.1 Results

The aim of this study was to explore climate change mitigation and adoption potentials for CCCs. The processes that can contribute to climate change or to climate change mitigation were described (chapter 1). An important conclusion was that C-sequestration is of much more importance than N-saving. In chapter 2, the methodology was described. Crop acreages have a rather high impact on both mitigation and adoption potentials estimated.

In chapter 3, it appeared that the arable cropping plans in the EU are dominated by cereals, industrial crops and plants green harvested. Under or after cereals and green maize, CCCs can generally be grown well. Further, olive is the biggest permanent crop, under which a CCC can be grown. This forms the basis for selection of casestudies, being NUTS2-regions in the first place. Finetuning can be carried out with information on the availability of moisture after the harvest of the main crop and the options for nitrogen saving, especially in regions with high rainfall figures. Estimations on cost-benefit ratios and the impact of policies provided additional information for understanding whether adoption is hindered or stimulated in practice. Moreover, information of management practices was presented, facilitating the design of the questionnaire in phase 2.

At the end of chapter 3, a shortlist was presented with 14 potential case study regions with the highest rankings on the combination of adoption and mitigation potentials in the EU. This list represents a diverse selection of MSs from a geographical, a crop rotational and a climatic point of view. This shortlist forms, together with the information on management practices and policies, a good basis for the final selection of case study regions in phase 2 of the study.

4.2 Methodology

The methodology applied in this study had to be an overall methodology, covering all MSs. Within the limitations of the project, this methodology needed to be rough, althoug the basis was well based on literature. However, ranges of what a CCC can produce in terms of biomass and, as a consequence, contribute to the climate change mitigation process, were wide. In practice, much more detailed information will be required for farmers to conclude whether growing CCCs is profitable in their specific situation, including crop rotation, farming system, nitrogen rates, climatic conditions, crop margins and policy requirements. Therefore, it is well possible that in practice

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Appendices

Appendix 1 Background information on the SAPM-study and on Eurostat definitions

SAPM-study

The Survey on agricultural production methods, abbreviated as SAPM, is a once-only survey carried out in 2010 to collect data at farm level on agri-environmental measures. European Union (EU) Member States could choose whether to carry out the SAPM as a sample survey or as a census survey. Data were collected on tillage methods, soil conservation, landscape features, animal grazing, animal housing, manure application, manure storage and treatment facilities and irrigation (http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Survey_on_agricultural_production_methods_(SAPM)).

Part of this survey dealt with soil cover and tillage practices. Respondents were asked to provide data on the area of arable land under soil cover and subject to various tillage practices. Both using less intrusive tillage and maintaining a soil cover during winter are two important practices that reduce soil degradation and help to prevent nutrient and pesticide runoff. The definition of crop cover in the SAPM-study is as follows: Arable land covered with cover crop or intermediate crop is an area of arable land on which plants are sown specifically to reduce the loss of soil, nutrients and plant protection products during the winter or other periods when the land would otherwise be bare and susceptible to losses. The economic interest of these crops is low, and the main goal is soil and nutrient protection. Normally they are ploughed in during spring before sowing another crop, and are not harvested or used for grazing. Agricultural land with no plant cover or where there are just plant residues on the top is especially vulnerable to soil erosion and nutrient and pesticide loss. In efforts to reduce losses which are harmful both to the environment and to the economy one of the most efficient tools is keeping the land covered with plants at all times. These crops should not be mistaken for normal winter crops or grassland (http://ec.europa.eu/eurostat/statistics-explained/index.php/Survey_on_agricultural_production_methods#Soil_cover_and_tillage_practices).

According to this definition, SAPM mostly counts cover crops during the winter period, but does not exclude CCC's grown during other periods. The sample method differs between countries: the maximum period is one year, but some countries only focussed on the winter period. No information was available about two CCC crops grown within one year. This is most probably an exception and also costly.

Definitions in Eurostat

Source: *http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary*

Arable land

Arable land, in agricultural statistics, is land worked (ploughed or tilled) regularly, generally under a system of crop rotation.

- Arable land
- Permanent grassland and meadow
- Permanent crops
- Other

Permanent grassland

Permanent grassland is land used permanently (for several - usually more than five - consecutive years)

- to grow herbaceous forage crops, through cultivation (sown) or naturally (self-seeded);
- not included in the crop rotation scheme on the agricultural holding.

Permanent grassland can be used for grazing by livestock or mown for hay, silage (stocking in a silo) or used for renewable energy production.

Three different types of permanent grassland are identified in the Farm structure survey (FSS):

- pasture and meadow, excluding rough grazing: permanent pasture on good or medium quality soils, which can normally be used for intensive grazing;
- rough grazings: low-yielding permanent grassland, usually on low-quality soil (for example on hilly land and at high altitudes), usually unimproved by fertiliser, cultivation, reseeding or drainage, which can normally be used only for extensive grazing and are normally not mown or are mown in an extensive manner and which cannot support a large density of animals;
- permanent grassland no longer used for production purposes and eligible for the payment of subsidies which, in line with Regulation (EU) No 1306/2013 or, where applicable, the most recent legislation, are maintained in good agricultural and environmental condition and are eligible for financial support.

Permanent crops

Permanent crops are ligneous crops, meaning trees or shrubs, not grown in rotation, but occupying the soil and yielding harvests for several (usually more than five) consecutive years. Permanent crops mainly consist of fruit and berry trees, bushes, vines and olive trees. The fruits of permanent crops are usually intended for human consumption and generally yield a higher added value per hectare than annual crops. They also play an important role in shaping the rural landscape (through orchards, vineyards and olive tree plantations) and helping to balance agriculture within the environment.

Definitions related to cover crops and soil cover

Winter crops

Arable land covered with normal winter crop is an area of arable land on which crops are sown in the autumn and growing during the winter (normal winter crops, such as winter wheat), normally harvested or used for grazing.

Arable land covered with cover crop or intermediate crop

Arable land covered with cover crop or intermediate crop is arable land on which crops are grown specifically to reduce the loss of soil, nutrients and plant protection products during the winter or other periods when the land would otherwise be bare and susceptible to losses. The economic interest of these crops is low, and the main goal is soil and nutrient protection. Normally, they are ploughed in during spring before sowing another (main) crop, and are not harvested or used for grazing. Agricultural land with no crop cover or where there are just plant residues on the top is especially vulnerable to soil erosion and nutrient and pesticide losses. In efforts to reduce losses which are harmful both to the environment and to the economy one of the most efficient tools is keeping the land covered with crops at all times. These crops should not be mistaken for normal winter crops or grassland.

Arable land covered with crop residues

Arable land covered with crop residues is arable land covered with the crop residues and stubbles of the previous crop season during winter. Intermediate and cover crops are excluded. Plants residues can be straw, stubble or other plants parts leaving good mulch (for example sugar beet leaves) regardless if they remain from the previous harvest or have been added by the farmer. Potatoes are normally excluded because the stalks are degraded too quickly. The tillage operations are in this case normally carried out in the spring. Certain tillage operations can be carried out in autumn, if they leave enough crop residues on the surface. Such tillage methods could be chisel or disk ploughing or similar. The straw can be removed for energy or other purposes, but an indicative threshold for remaining residue is a minimum of 10%. Self-grown cereals covering the soil after a tillage operation is included.

Arable land with bare soil

Arable land with bare soil is arable land that is ploughed or otherwise tilled in autumn and is not sown or covered during winter with any plant residues, remaining bare until the pre-seeding or seeding agro-technical operations in the following spring period. Arable land on which tillage methods leave more than 10% of plant residues on the surface are recorded under "plant residues".

Soil cover

Soil cover refers to vegetation, including crops, and crop residues on the surface of the soil. Various farming practices can be used in order to reduce soil degradation. Maintaining the cover of the soil during winter is one of such practices that reduce soil erosion and the loss of particulate pollutants (i.e. those attached to soil) including nutrients, plant protection products and faecal microbes. This practice also increases soil organic matter. Agricultural land with no crop cover or where there are just crop residues on the top is especially vulnerable to nutrient leakage.

In some EU Member States requirements to either have normal winter crops like winter wheat or cover crops are included in legislation or are part of the agri-environmental schemes farmers can adhere to. These crops should not be mistaken for normal winter green crops, such as winter wheat which is to be harvested or grassland. These are crops sown in the autumn with the sole aim to reduce nutrient leakage. Normally they are ploughed in during spring before sowing another crop, and are not harvested or used for grazing. The following categories are defined under soil cover:

- arable land covered with normal winter crop,
- arable land covered with cover crop or intermediate crop,
- arable land covered with plant residues,
- arable land with bare soil.

Data on soil cover of arable land were collected in the Farm structure survey (FSS) 2003 and in the Survey on agricultural production methods (SAPM).

Appendix 2A Overview of catch and cover crops in the EU: glossary of species in different languages

				Languages	
	Latin name	English name	German name	French name	Danish name
Annual cereals	Avena strigosa	Black/lopsided/bristle oat	Rau/Sand-hafer	Avoine rude	Pur havre
Annual or perennial cereals	Secale cereale	Rye	Roggen	Seigle	Rug/Almindelig
	Secale multicaule	Wild rye	Waltstaudenroggen/ Johannisroggen/ Futterroggen	Seigle pérenne	Stauderug
	Triticale	Triticale	Triticale	Triticale	Triticale
	Avena sativa	Oat/Common oat	Saat-Hafer/Echter Hafer/Schwarzhafer/ Schwarzer Hafer	Avoine cultivée/ Avoine commune/ Avoine byzantine/ Avoine	Almindelig Havr
	Hodeum vulgare	Barley	Gerste	Orge	Byg
	Triticum aestivum	Winter wheat	Weichweizen/ Saat-weizen/Brotweizen	Blé tendre/Froment	Brød-Hvede/ Almindelig Hved
Annual or perennial grasses	Festuca pratensis	Meadow fescue	Wiesen-schwingel	Fetuque des pres	Engsvingel
	Lolium perenne	English ryegrass	Deutsches weidelgras	Ray-grass Anglais/commun/ Ivraie vivace	Almindelig rajgr
	Lolium sp. x Festuca sp.	Hybrid fescue	Schwingel-Lolch	Fétugue hybride	Eng-Svingel x Almindelig Rajgr
	Lolium multiflorum	Italian/Annual ryegrass	Italienische Raygras/ Italienisches Weidelgras	Ray-grass d'Italie	Italiensk rajgræ
	Festuca arundinacea	Tall fescue	Rohr-Schwingel	Fétuque élevée/fétuque roseau/fétuque faux-roseau	Strand-svingel
	Phleum pratense	Timothy	Wiesenlieschgras	Fléole des prés	Engrottehale
	Poa pratensis	(Kentucky) blue grass, smooth/common meadow-grass	Wiesen-rispengras	Pâturin des prés	Eng-Rapgræs
Warm-season grasses	Sorghum bicolor	Sorghum/great millet/durra/jowari/milo	Mohrenhirse/Sorgho/ Dari/Durrakorn	Sorghum/sorgo commun	Ægte durra
	Pennisetum glaucum	Pearl Millet	Perlhirse	Mil à chandelle/Mil	Perlehirse
	Setaria italica	Foxtail millet/Dwarf setaria/Foxtail bristle-grass/Giant setaria/Green foxtail/Italian millet/German millet/Hungarian millet	Kolbenhirse/ Borstenhirse	Sétaire d'Italie/Panis/Millet des oiseaux/Petit mil	Kolbehirse
	Setaria italica subsp. Italica	Foxtail millet	Gewöhnliche Italienische Borstenhirse/Große Kolbenhirse/Fennich	**n.a.**	**n.a.**
	Setaria italica subsp. Moharia	**n.a.**	Mohar/Kleine kolbenhirse	**n.a.**	**n.a.**
Brassicas and mustards	Brassica napus	oilseed rape	Körnerraps/Futterraps	Colza	Rapsfrø
	Brassica napus oleifera		Körnerraps		
	Brassica rapa L. var. sylvestris	Turnip rape	Ölrübsen	Navette	Rybs
	Raphanus longipinnatus sp.	Daikon/Daikon radish/ Tillage radish/Forage radish/Fodder radish	Winterrettich/ Chinesischer rettich/ Japanischer Rettich/ Daikon/Pinyin	Radis blanc/Radis d'hiver/Radis chinois	Kinaradisen/Jap Rædike

	Raphunus sativus	Oil radish	Ölrettich	Radis oléifère	Olie-ræddike
	Camelina sativa	Camelina/gold-of-pleasure/ False flax	Leindotter/Saat-leindotter/Dotterlein	Lin bâtard/sésame d'Allemagne	Sæd-Dodder
	Brassica carinata	Ethiopian mustard	Abessinischer/ Äthiopischer Senf	Moutarde d'abyssinie	Etiopisk sennep
	Sinapsis alba	White mustard	Weißer senf/Gelbsenf	Moutarde blanche/ Sénevé	Gul sennep
	Brassica juncea	Brown mustard	Braune senf/ Indischer senf/ Sareptasenf/ Ruten-Kohl	Moutarde brune/ Moutarde chinoise	Sareptasennep
	Brassica rapa var. rapa	Turnip	Speiserübe	Navet potager	Majroe
	Eruca sativa	Rocket salad/rucola/colewort	Garten-senfrauke	Roquette	Rucola/Senneps Salatsennep
Legumes	Trifolium Alexandrinum	Egyptian clover/Berseem clover	Ägyptische/ Alexandriner Klee	Trèfle d'Alexandrie/ Trèfle de Bersim	Aleksandriner-kløver
	Pisum sativum	Pea	Erbse/Gartenerbse/ Speiseerbse/Futtererbse	Pois cultivé	Almindelig Ært
	Vigna unguiculata	Cowpea	Augenbohne/Kuhbohne/ Schwarzaugenbohne/ Schlangenbohne	Niébé/Haricot à l'œil noir/Cornille/Banette/Voème	Vignabønne
	Trifolium incarnatum	Crimson/Italian clover	Inkarnat-Klee/Blutklee/ Rosenklee/ Italienischer Klee	Trèfle du Rousillon	Blodkløver
	Lupinus angustifolius	Blue lupin/narrowleaf lupin	Blaue/Schmallblättrige lupine	Lupin réticulé	Smalbladet lupi
	Trifolium resupinatum	Reversed/Persian clover/ shaftal	Persische Klee/ Wendeklee	Trèfle de Perse/ renversé	Perserkløver
	Trifolium pratense	Red clover	Wiesenklee/Rotklee	Trèfle des prés/ Trèfle violet	Rødklover/ rød-klover
	Trifolium subterraneum	Subterranean clover/ Sub clover	Bodenfrüchtige Klee	Trèfle souterrain	Jord-kløver
	Vicia sativa	Common vetch/Garden vetch/Tare/Vetch	Futterwicke/Saat-wicke	Vesce commune/ Vesce cultivée	Fodervikke
	Vicia benghalensis	Purple vetch/Reddish tufted vetch	Bengbakische Wicke	Vesce du Bengale	Bengalsk vikke
	Ornithopus sativa	Serradella	Serradella	Serradelle	Serradel
	Vicia villosa.	Winter vetch/Hairy vetch	Zottige wicke	Vesce velue	Sandvikke/ San vikke
	Vicia villosa ssp. Varia	Woollypod vetch	Bunte Wicke	Vesce bigarrée	Glat Vikke
	Trifolium repens	White clover/Dutch clover/ Ladino clover	Weißklee/Kriechklee	Trèfle blanc/ Trèfle rampant	Hvidkløver/ Hvi kløver
	Medicago spp.	Medick/Burclover	Schneckenklee	luzernes	Sneglebælg
	Medicago sativa	Alfalfa/Lucerne	Luzerne/Saat-Luzerne/ Alfalfa/Schneckenklee/ Ewiger Klee	Luzerne cultivée/ alfalfa/alfa-alfa	Lucerne/Alfalfa
	Lupinus species	Lupin/Lupine	Lupinen/Wolfsbohne/ Feigbohne	Lupins	Lupin/Ulvebønn
	Onobrychis viciifolia	Common sainfoin	Saat-Esparsette/ Futter-Esparsette	Sainfoin cultivé/ Esparcette cultivée/ Esparcette à feuilles de vesce	Foderesparsette Esparsette
	Melilotus officinalis	Yellow sweet clover/ Yellow melilot/Ribbed melilot/ common melilot	Gelbe Steinklee/ Gewöhnlicher Steinklee/ Echter Steinklee/ Gebräuchlicher Steinklee/Honigklee	Mélilot officinal/ Mélilot jaune	Mark-Stenkløve
	Lotus corniculatus	Common bird's-foot trefoil/ Bird's-foot trefoil/Bird's-foot deervetch	Gewöhnliche Hornklee/ Gemeiner Hornklee/ Schotenklee	Lotier corniculé	Almindelig kællingetand
	Vicia faba	Broad bean/Fava bean/ Faba bean/Field bean/Bell bean/ Tic bean	Ackerbohne/Saubohne/ Schweinsbohne/ Favabohne/Dicke Bohne/Große Bohne/ Pferdebohne/Viehbohne/Faberbohne/ Puffbohne	Fèves/Féveroles	Hestebønne/ Favabønne/Vals bønne/Vælsk bønne
Others	Fagopyrum esculentum	Buckwheat	Echte Buchweizen/ Gemeiner Buchweizen	Sarrasin	Almindelig boghvede

Phacelia tanacetifolia	Phacelia	Rainfarn-Phazelie/ Büschelschön	Phacélie à feuilles de tanaisie	Almindelig honningurt/ Honningurt
Helianthus annuus	Common sunflower	Sonnenblume/ Gewöhnliche Sonnenblume	Tournesol	Almindelig Solsikke/ Solsik
Lens nigricans	Black lentil	Schwarze Linse	Lentille noirâtre/ Lentille sauvage	
Lens culinaris	Lentil	Linse/Erve/Küchen-Linse	Lentille cultivée/Lentille comestible ou lentille	
Fagopyrum tataricum	Tartary buckwheat/Green buckwheat/Ku qiao/Bitter buckwheat	Tatarische Buchweizen/ Falscher Buchweizen	Sarrasin de Tartarie/ Noir fourrager	Tatarisk Boghve
Guizotia abyssinica	Niger	Ramtillkraut/ Gingellikraut	Nyger/Noog	Nigerfrø/Niger
Tagetes Patula	Tagetes	Tagetes/ Studentenblume/ Sammetblume/ Türkische Nelke/ Totenblume	Tagètes/Tagettes	Fløjlsblomst
Solanum sisymbriifolium	Vila-vila/Sticky nightshade/Red buffalo-bur/Fire-and-ice plant/Litchi tomato/Morelle de Balbis	Raukenblättrige Nachtschatten/Klebrige Nachtschatten	Morelle de Balbis/ Tomate Litchi/ Morelle à feuille de Sisymbrium	Solanum sisymbriifolium
Spergula arvensis	Corn spurry	Acker-Spark/Acker-Spörgel/Feld-Spark	Spergule des champs/Spargoute des champs/ Espargoutte des champs/Spargelle	Almindelig sperg Spergel
Linum usitatissimum	Flax	Gemeiner Lein/Saat-Lein/Flachs	Lin cultivé	Almindelig hør

Appendix 2B Overview of catch and cover crops in the EU

	Languages		Tolerances					
	Latin name	English name	Heat	Drought	Shade	Flood	Low fertility	Min. Germ Temp °C
Annual cereals	Avena strigosa	Black/lopsided/bristle oat						
Annual or perennial cereals	Secale cereale	Rye	***	****	****	***	*****	1.1
	Secale multicaule	Wild rye						
	Triticale	Triticale						
	Avena sativa	Oat/Common oat	**	**	**	***	***	3.3
	Hodeum vulgare	Barley	****	****	***	**	****	3.3
	Triticum aestivum	Winter wheat	***	***	***	*	***	3.3
Annual or perennial grasses	Festuca pratensis	Meadow fescue						
	Lolium perenne	English ryegrass						
	Lolium sp. x Festuca sp.	Hybrid fescue						
	Lolium multiflorum	Italian/Annual ryegrass	**	**	****	****	**	4.4
	Festuca arundinacea	Tall fescue						
	Phleum pratense	Timothy						
	Poa pratensis	(Kentucky) blue grass, smooth/common meadow-grass						
Warm-season grasses	Sorghum bicolor	Sorghum/great millet/durra/jowari/milo	*****	*****	***	***	***	18.3
	Pennisetum glaucum	Pearl Millet						
	Setaria italica	Foxtail millet/Dwarf setaria/Foxtail bristle-grass/Giant setaria/Green foxtail/Italian millet/German millet/Hungarian millet						
	Setaria italica subsp. Italica	Foxtail millet						
	Setaria italica subsp. Moharia	**n.a.**						
Brassicas and mustards	Brassica napus	oilseed rape	**	***	***	**	**	5
	Brassica napus oleifera		**	***	***	**	**	5
	Brassica rapa L. var. sylvestris	Turnip rape						
	Raphanus longipinnatus sp.	Daikon/Daikon radish/ Tillage radish/Forage radish/Fodder radish	***	**	***	**	**	7.2
	Raphunus sativus	Oil radish	***	**	***	**	**	7.2
	Camelina sativa	Camelina/gold-of-pleasure/ False flax						
	Brassica carinata	Ethiopian mustard	***	****	***	**	**	4.4
	Sinapsis alba	White mustard	***	****	***	**	**	4.4
	Brassica juncea	Brown mustard	***	****	***	**	**	4.4
	Brassica rapa var. rapa	Turnip						

	Eruca sativa	Rocket salad/rucola/colewort						
Legumes	Trifolium Alexandrinum	Egyptian clover/Berseem clover	****	***	****	***	***	5.6
	Pisum sativum	Pea	**	***	**	**	**	5
	Vigna unguiculata	Cowpea	*****	****	***	**	*****	14.4
	Trifolium incarnatum	Crimson/Italian clover	***	**	****	**	***	
	Lupinus angustifolius	Blue lupin/narrowleaf lupin						
	Trifolium resupinatum	Reversed/Persian clover/ shaftal						
	Trifolium pratense	Red clover	**	**	****	***	**	5
	Trifolium subterraneum	Subterranean clover/ Sub clover	***	****	****	***	*****	3.3
	Vicia sativa	Common vetch/Garden vetch/Tare/Vetch						
	Vicia benghalensis	Purple vetch/Reddish tufted vetch						
	Ornithopus sativa	Serradella						
	Vicia villosa.	Winter vetch/Hairy vetch	**	***	***	**	**	15.6
	Vicia villosa ssp. Varia	Woollypod vetch	****	****	***	***	****	
	Trifolium repens	White clover/Dutch clover/ Ladino clover	***	***	****	****	***	4.4
	Medicago spp.	Medick/Burclover	*****	****	****	**	***	7.2
	Medicago sativa	Alfalfa/Lucerne	*****	****	****	**	***	7.2
	Lupinus species	Lupin/Lupine						
	Onobrychis viciifolia	Common sainfoin						
	Melilotus officinalis	Yellow sweet clover/ Yellow melilot/Ribbed melilot/ common melilot	****	*****	**	**	*****	5.6
	Lotus corniculatus	Common bird's-foot trefoil/ Bird's-foot trefoil/Bird's-foot deervetch						
	Vicia faba	Broad bean/Fava bean/ Faba bean/Field bean/Bell bean/ Tic bean						
Others	Fagopyrum esculentum	Buckwheat	***	*	**	**	**	10
	Phacelia tanacetifolia	Phacelia						
	Helianthus annuus	Common sunflower						
	Lens nigricans	Black lentil						
	Lens culinaris	Lentil						
	Fagopyrum tataricum	Tartary buckwheat/Green buckwheat/Ku qiao/Bitter buckwheat						
	Guizotia abyssinica	Niger						

	Tagetes Patula	Tagetes						
	Solanum sisymbriifolium	Vila-vila/Sticky nightshade/Red buffalo-bur/Fire-and-ice plant/Litchi tomato/Morelle de Balbis						
	Spergula arvensis	Corn spurry						
	Linum usitatissimum	Flax						

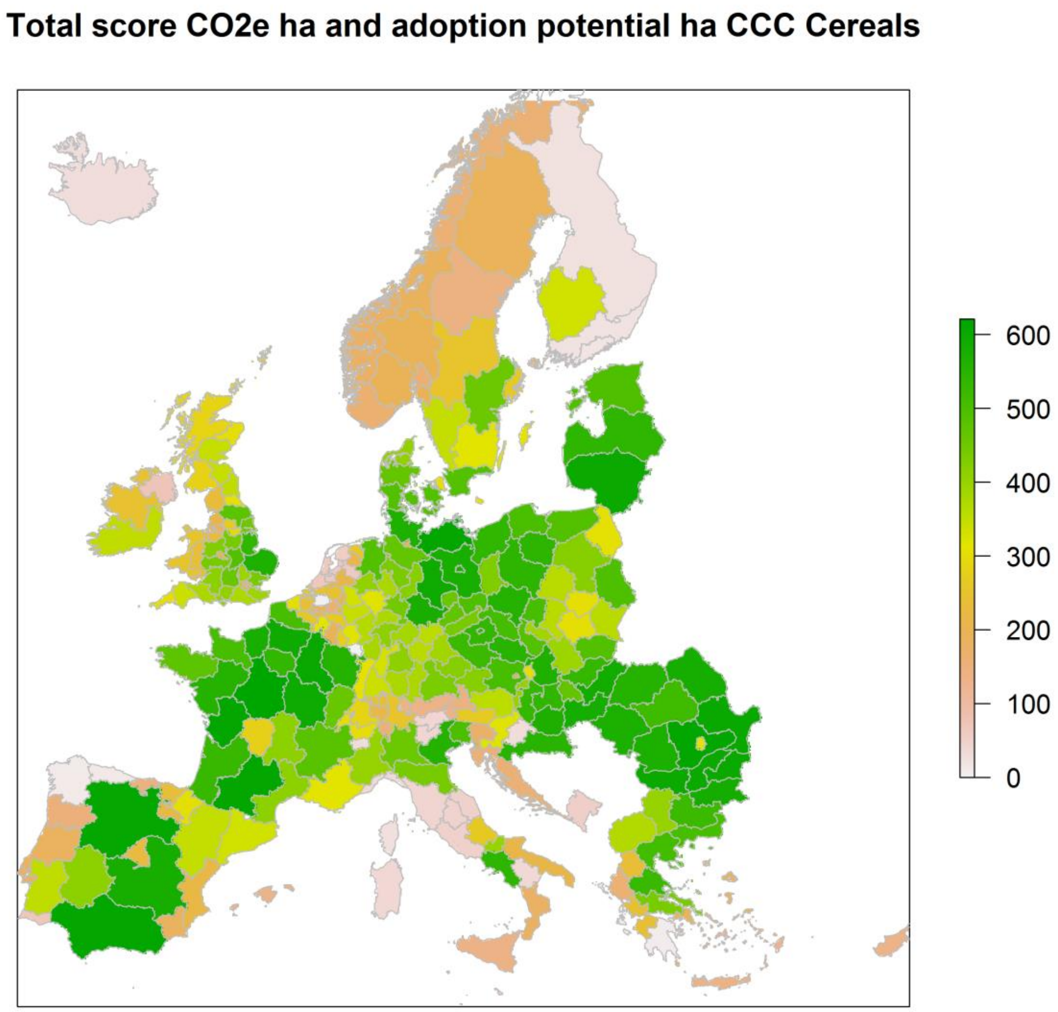
* : Poor
** : Fair
*** : Good
**** : Very good
***** : Excellent

Appendix 2C Overview of catch and cover crops in the EU: sowing periods

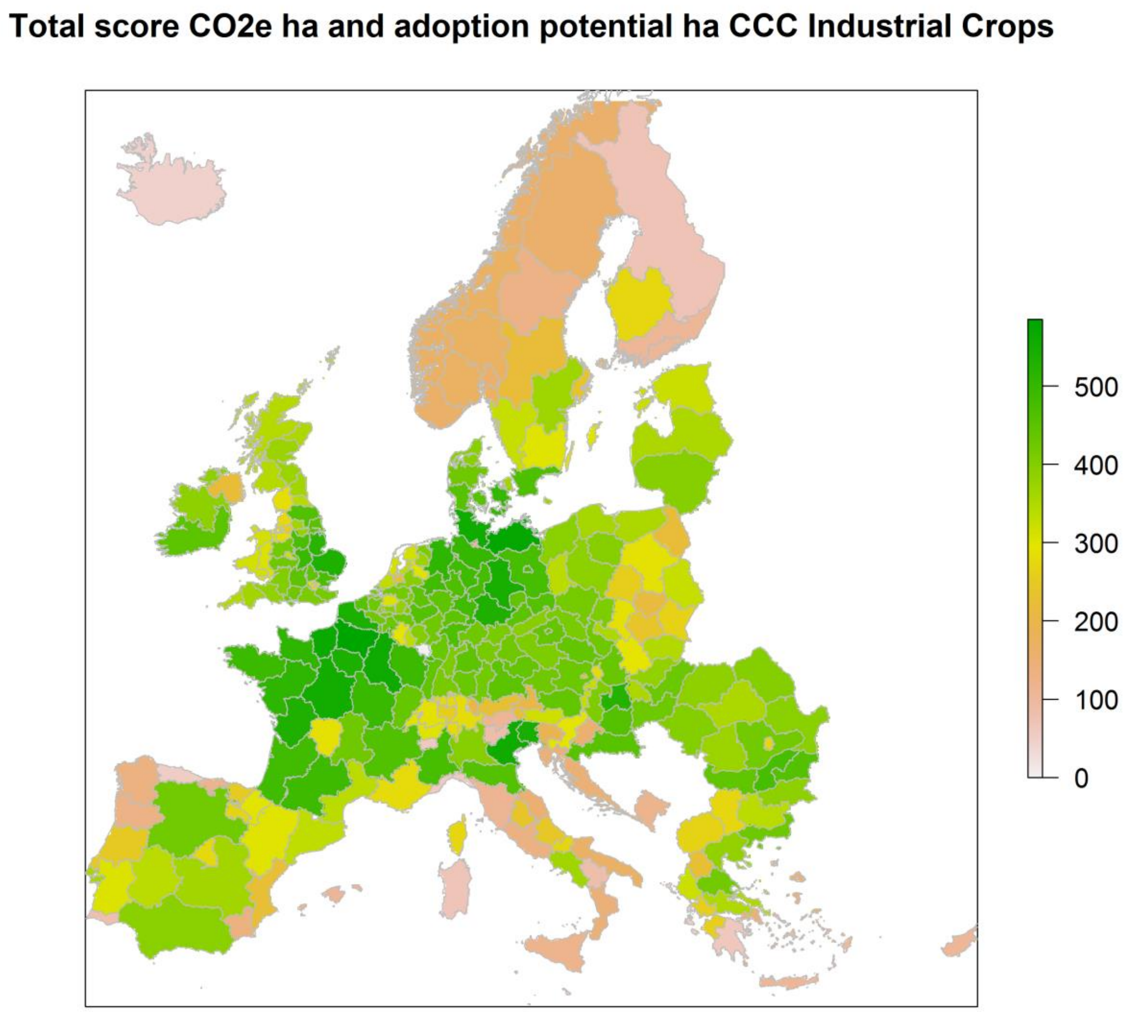
	Languages		Sowing				
	Latin name	English name	March	April	May	June	July
Annual cereals	Avena strigosa	Black/lopsided/bristle oat					
Annual or perennial cereals	Secale cereale	Rye					
	Secale multicaule	Wild rye					
	Triticale	Triticale					
	Avena sativa	Oat/Common oat					
	Hodeum vulgare	Barley					
	Triticum aestivum	Winter wheat					
Annual or perennial grasses	Festuca pratensis	Meadow fescue					
	Lolium perenne	English ryegrass					
	Lolium sp. x Festuca sp.	Hybrid fescue					
	Lolium multiflorum	Italian/Annual ryegrass					
	Festuca arundinacea	Tall fescue					
	Phleum pratense	Timothy					
	Poa pratensis	(Kentucky) blue grass, smooth/common meadow-grass					
Warm-season grasses	Sorghum bicolor	Sorghum/great millet/durra/jowari/milo					
	Pennisetum glaucum	Pearl Millet					
	Setaria italica	Foxtail millet/Dwarf setaria/Foxtail bristle-grass/Giant setaria/Green foxtail/Italian millet/German millet/Hungarian millet					
	Setaria italica subsp. Italica	Foxtail millet					
	Setaria italica subsp. Moharia	**n.a.**					
Brassicas and mustards	Brassica napus	oilseed rape					
	Brassica napus oleifera						
	Brassica rapa L. var. sylvestris	Turnip rape					
	Raphanus longipinnatus sp.	Daikon/Daikon radish/ Tillage radish/Forage radish/Fodder radish					
	Raphunus sativus	Oil radish					
	Camelina sativa	Camelina/gold-of-pleasure/ False flax					
	Brassica carinata	Ethiopian mustard					
	Sinapsis alba	White mustard					
	Brassica juncea	Brown mustard					
	Brassica rapa var. rapa	Turnip					
	Eruca sativa	Rocket salad/rucola/colewort					
Legumes	Trifolium Alexandrinum	Egyptian clover/Berseem clover					

	Pisum sativum	Pea
	Vigna unguiculata	Cowpea
	Trifolium incarnatum	Crimson/Italian clover
	Lupinus angustifolius	Blue lupin/narrowleaf lupin
	Trifolium resupinatum	Reversed/Persian clover/ shaftal
	Trifolium pratense	Red clover
	Trifolium subterraneum	Subterranean clover/ Sub clover
	Vicia sativa	Common vetch/Garden vetch/Tare/Vetch
	Vicia benghalensis	Purple vetch/Reddish tufted vetch
	Ornithopus sativa	Serradella
	Vicia villosa.	Winter vetch/Hairy vetch
	Vicia villosa ssp. Varia	Woollypod vetch
	Trifolium repens	White clover/Dutch clover/ Ladino clover
	Medicago spp.	Medick/Burclover
	Medicago sativa	Alfalfa/Lucerne
	Lupinus species	Lupin/Lupine
	Onobrychis viciifolia	Common sainfoin
	Melilotus officinalis	Yellow sweet clover/ Yellow melilot/Ribbed melilot/ common melilot
	Lotus corniculatus	Common bird's-foot trefoil/ Bird's-foot trefoil/Bird's-foot deervetch
	Vicia faba	Broad bean/Fava bean/ Faba bean/Field bean/Bell bean/ Tic bean
Others	Fagopyrum esculentum	Buckwheat
	Phacelia tanacetifolia	Phacelia
	Helianthus annuus	Common sunflower
	Lens nigricans	Black lentil
	Lens culinaris	Lentil
	Fagopyrum tataricum	Tartary buckwheat/Green buckwheat/Ku qiao/Bitter buckwheat
	Guizotia abyssinica	Niger
	Tagetes Patula	Tagetes
	Solanum sisymbriifolium	Vila-vila/Sticky nightshade/Red buffalo-bur/Fire-and-ice plant/Litchi tomato/Morelle de Balbis
	Spergula arvensis	Corn spurry
	Linum usitatissimum	Flax

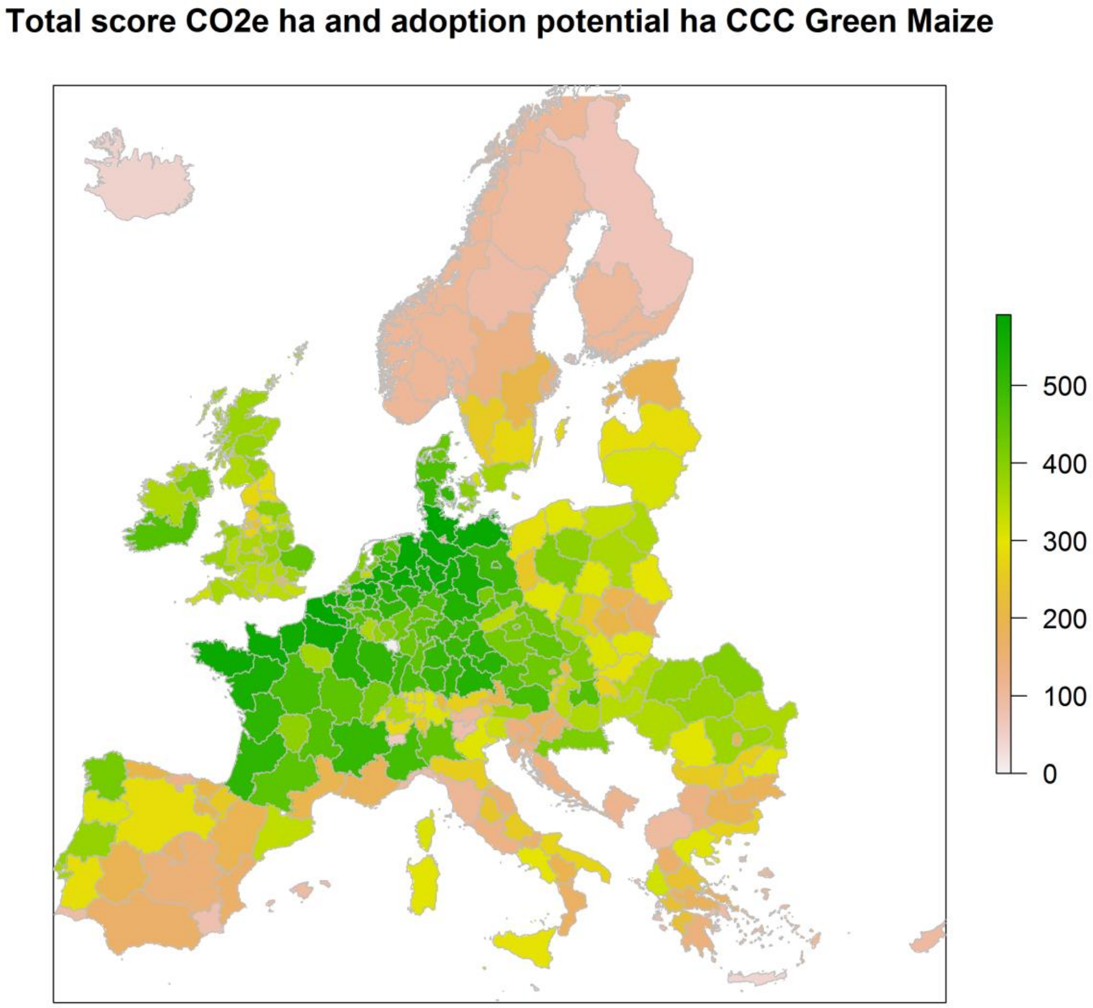
Appendix 3 Combined potentials and total mitigation potential for big crop groups



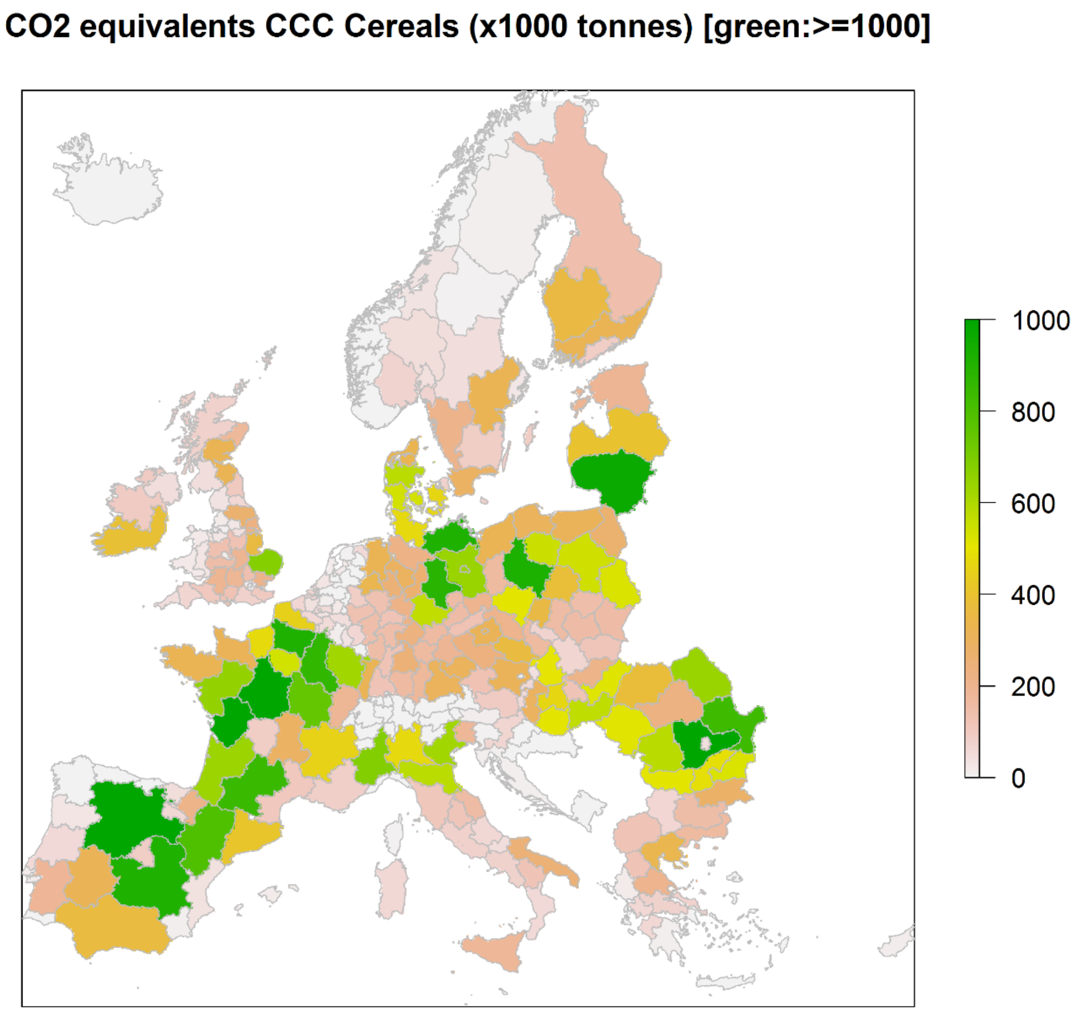
Map A3.1 Sum of rankings of climate change mitigation and adoption potentials for cereals per NUTS2-region. Source: Own estimations as explained in the text.



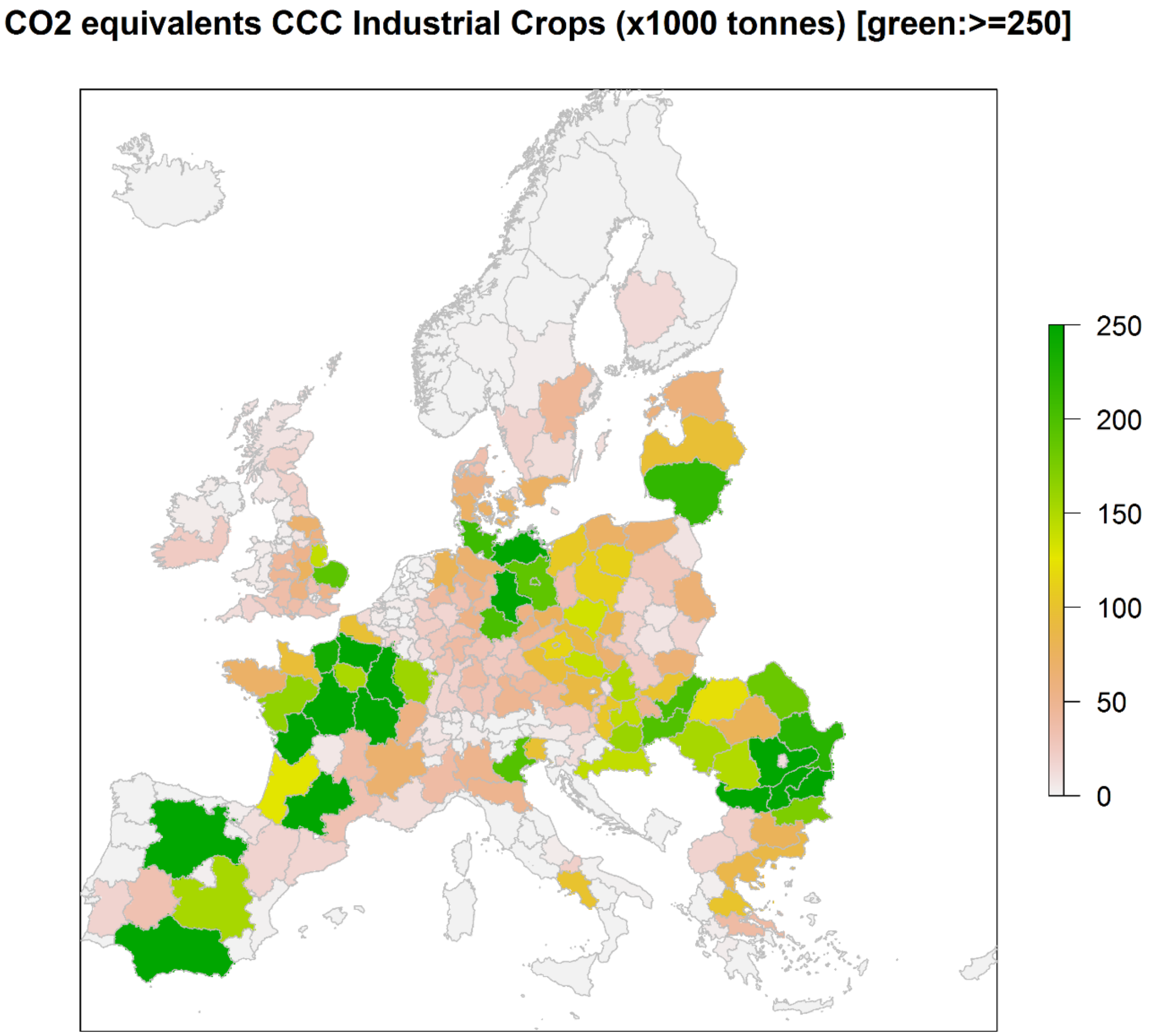
Map A3.2 Sum of rankings of climate change mitigation and adoption potentials for industrial crops per NUTS2-region. Source: Own estimations as explained in the text.



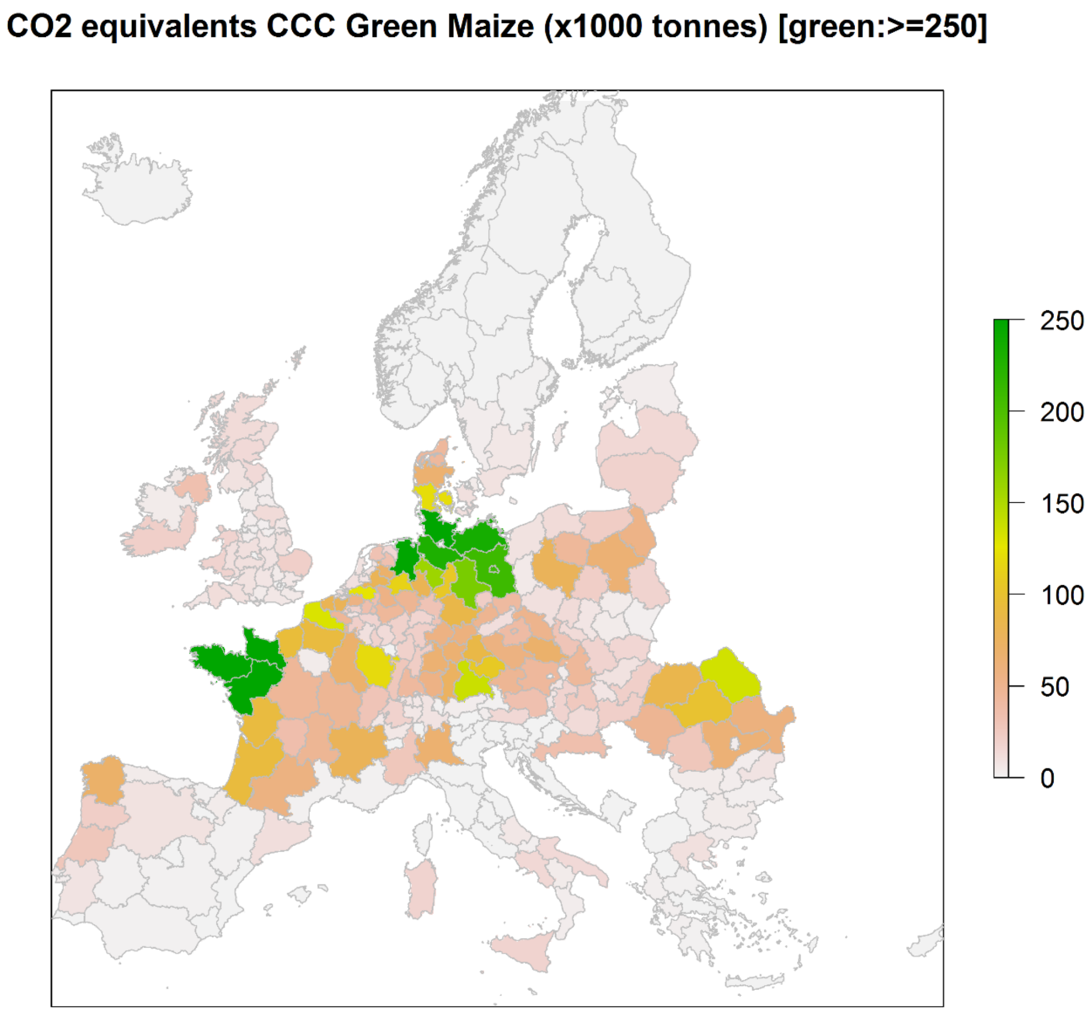
Map A3.3 Sum of rankings of climate change mitigation and adoption potentials for green maize per NUTS2-region. Source: Own estimations as explained in the text.



Map A3.4 Total mitigation potentials (in kton CO2 per year) for cereals per NUTS-region. Source: Own estimations as explained in the text.

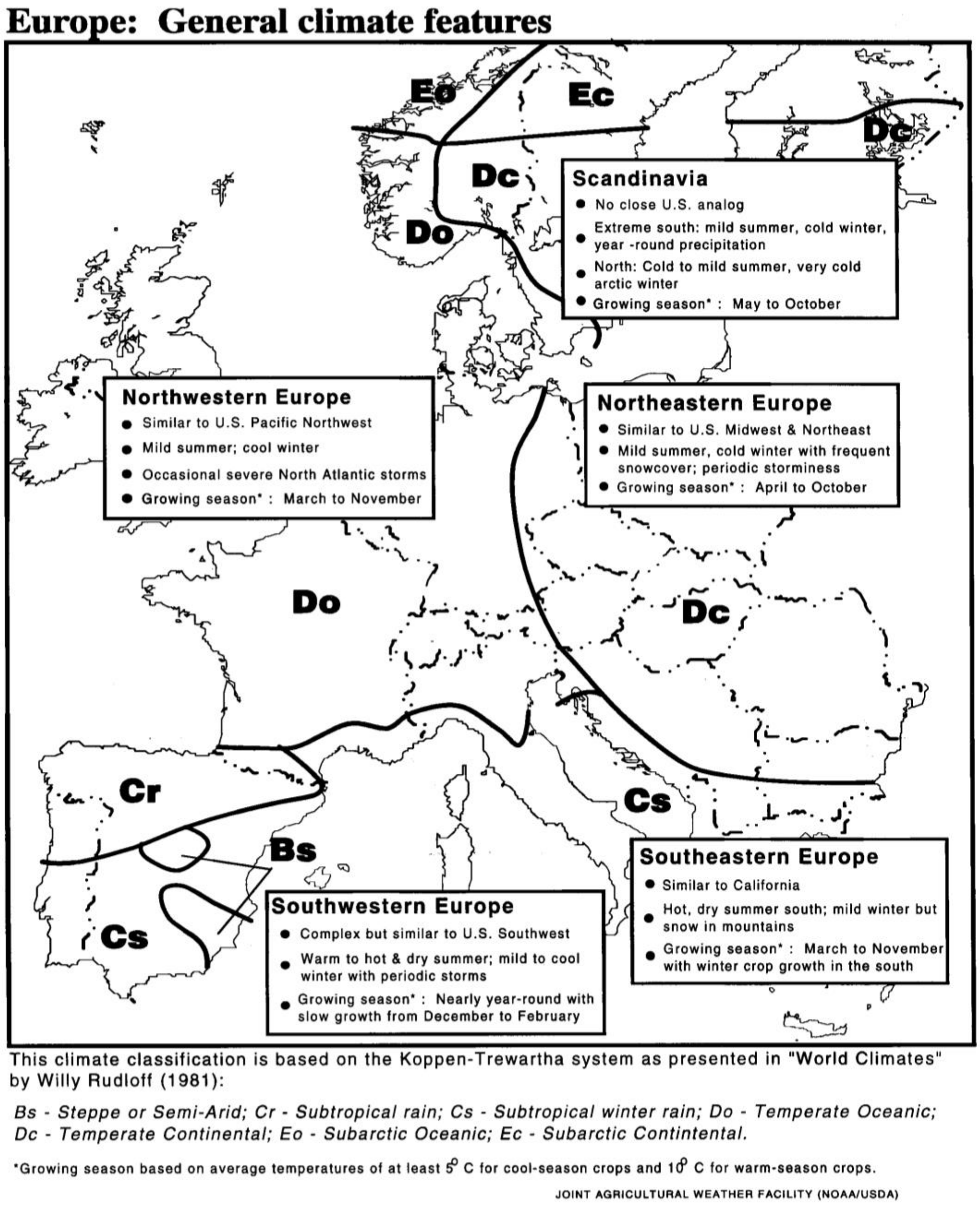


Map A3.5	Total mitigation potentials (in kton CO2 per year) for industrial crops per NUTS-region.
Source: Own estimations as explained in the text.



Map A3.6 Total mitigation potentials (in kton CO2 per year) for green maize per NUTS-region.
Source: Own estimations as explained in the text.

Appendix 4 Additional information about climatic zones



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Map A4.1 Climate classification according to Köppen-Trewartha.